National Aeronautics and Space Administration

Technology Evaluation for Environmental Risk Mitigation Principal Center (TEERM)

Hexavalent Chrome Free Coatings for Electronics Applications

Joint Test Report

January 2013

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1 Introduction

1.1 Background

Regardless of the corrosivity of the environment, all metals require periodic maintenance activity to guard against the insidious effects of corrosion and thus ensure that alloys meet or exceed design or performance life. The standard practice for protecting metallic substrates is the application of a coating system. Applied coating systems work via a variety of methods (barrier, galvanic, and/or inhibitor) and adhere to the substrate through a combination of chemical and physical bonds. For years hexavalent chromium has been a widely used element within applied coating systems because of its self-healing and corrosion resistant properties. Occupational Safety and Health Administration (OSHA) studies have concluded that hexavalent chromium (hex chrome) is carcinogenic and poses significant risk to human health. On May 5, 2011 amendments to the Defense Federal Acquisition Regulation Supplement (DFARS) were issued in the Federal Register. Subpart 223.73 prohibits contracts from requiring hexavalent chromium in deliverables unless certain exceptions apply. These exceptions include authorization from a general or flag officer and members of the Senior Executive Service from a Program Executive Office, and unmodified legacy systems. Otherwise, Subpart 252.223-7008 provides the contract clause prohibiting contractors from using or delivering hexavalent chromium in a concentration greater than 0.1 percent by weight for all new contracts and to be included down to subcontractors for supplies, maintenance and repair services, and construction materials. National Aeronautics and Space Administration (NASA), Department of Defense (DoD), and industry stakeholders continue to search for alternatives to hex chrome in coatings applications that meet their performance requirements in corrosion protection, cost, operability, and health and safety, while typically specifying that performance must be equal to or greater than existing systems.

1.2 Objective

The overall objective of the Hexavalent Chrome Free Coatings for Electronics Applications project is to evaluate and test pretreatments not containing hexavalent chrome in avionics and electronics housing applications. This objective will be accomplished by testing strong performing coating systems from prior NASA and DoD testing or new coating systems as determined by the stakeholders.

2 Materials

2.1 Alloys

The following alloys have been selected because of their relatively common use in avionics and electronics housing systems and/or their ability to exhibit similar performance to other materials of interest. Table 1 lists the alloys on which coatings were applied and the entities given credit for procurement. All panels were procured mill finished without mill markings. Mill finish is as supplied from the mill (raw material manufacturer); is not polished and will most likely have a dull matte appearance.

Table 1 - Alloys Procured

Alloy	Size	Procuring Entity
6061-T6 Aluminum	3" X 10" X .032"	Rockwell Collins
7075-T73 Aluminum	3" X 10" X .032"	Lockheed Martin & Raytheon
2024-T3 Aluminum	3" X 10" X .032"	Lockheed Martin
5052-H32 Aluminum	3" X 10" X .032"	Harris Corp

2.2 Panel Preparation

The panel preparation procedure was developed as part of the NASA TEERM Hexavalent Chrome Alternatives for Aerospace Project. Stakeholders participating in the Hexavalent Chrome Free Coatings for Electronics Applications Project agreed to use the following procedure:

1. Solvent Hand Cleaning
   a. Ethanol {200 proof}.
2. Mild Alkaline Aqueous Degreaser (Non-Silicate)
   a. Chemetall-Oakite NST – (5% by volume @ 49° - 54°C for 4 minutes.)
3. DI water rinse to water break-free. Preceding degreasing steps will be repeated until water break-free is achieved.
4. Deoxidize Bath (Oakite LNC)
   a. Oakite LNC (10% by volume @ ambient temperature for 3 - 4 minutes.)
5. Rinse thoroughly using clean (5 megaohm or better) DI ambient temperature water.
6. Take panels directly to pretreatment bath

2.3 Pretreatments

Table 2 lists the pretreatments that were tested under the Hexavalent Chrome Free Coatings for Electronics Applications project. Some limited tests was also performed on vendor-supplied pretreatments (see Section 3.9).

Table 2 - Pretreatment Procurement

Pretreatment	Approved per MIL DTL 81706	Manufacturer
Alodine 1600	Type I Class 1A,3 Form I Method C	Henkel
Metalast HFEPA	Type II Class 1A Form I Method A,B,C	Metalast
Metalast HF	Type II Class 1A,3 Form 1 Method A,B,C	Metalast
SurTec 650 – chromitAL TCP	Type II Class 1A,3 Form I Method A,B,C	SurTec
SurTec 650 C	Type II Class 1A,3 Form I Method A,B,C	SurTec
Alodine T 5900 RTU	Type II Class 1A,3 Form III Method A,B,C	Henkel
Iridite NCP	Type II Class 3 Form I Method A,B,C	MacDermid

3 Pretreatment Testing

MIL-DTL-81706 is the specification to which pretreatments are qualified. Class 1A refers to the classification of pretreatments used for maximum corrosion protection while Class 3 refers to the classification of pretreatments with low electrical resistivity. The technical stakeholders agreed that this project be focused specifically on Class 3 coatings. The performance requirements and related tests are listed in Table 3. These tests were agreed upon by the stakeholders that participated in Hexavalent Chrome Free Coatings for Electronics Applications Project.

All testing was conducted at the NASA Kennedy Space Center (KSC) Corrosion Technology Laboratory and Beachside Corrosion Laboratory.

Table 3 – Pretreatment Testing

Test	Test Method	Evaluation Criteria	Performing Entity
Salt Spray Resistance	ASTM B 117	No evidence of corrosion when compared to unexposed control panels using the naked eye	NASA KSC
Cyclic Corrosion	ASTM G 85, Annex 5	No evidence of corrosion when compared to unexposed control panels using the naked eye	NASA KSC
18-Month Marine Environment	ASTM D 1014	No evidence of corrosion when compared to unexposed control panels using the naked eye	NASA KSC
PATTI JR Pull Test	ASTM D 4541		NASA KSC
Cross-Cut Tape Test	ASTM D 3359	ASTM D 3359, Method B, Figure1, Classification of Adhesion Test Results	NASA KSC
Wet Tape Paint Adhesion	FED STD 141, Method 6301.3	ASTM D 3359, Method A	NASA KSC
Surface Resistance	ASTM D 257	N/A	NASA KSC
Contact Electrical Resistance	MIL-DTL-81706	Not greater than 5,000 microhms psi as applied and 10,000 microhms psi after salt spray exposure	NASA KSC

3.1 Salt Spray Resistance

This test is used to rapidly evaluate the performance of a coating or coating system and how well it prevents corrosion. Salt Spray Resistance is a requirement of MIL-DTL-81706B.

3.1.1 Test Procedure

Test panels were subjected to a 5 percent NaCl salt spray, pH-adjusted to a range of 6.5 – 7.2, in accordance with ASTM B 117 (Standard Practice for Operating a Salt Spray (Fog) Apparatus).

There were sixteen (16) replicates per substrate / per coating system. One specimen from each substrate and coating system pairing was stored and used as an unexposed control. Five specimens from each substrate and coating system pairing were used for contact electrical resistance (MIL-DTL-81706B) and serve as the "before exposure" reading. Another five specimens underwent salt spray resistance then contact electrical resistance (MIL-DTL- 81706B) and serve as the "after exposure" reading. The last five were used for surface resistance testing (ASTM D 257), then underwent salt spray resistance, and then reevaluated for surface resistance (ASTM D 257).

3.1.2 Evaluation Procedure

For this effort, the following criteria were used when evaluating the test panels; MIL-DTL-81706B, section 3.5.1;"the specimens shall show no evidence of corrosion when compared to unexposed control panels using the naked eye. Areas within 0.25 inch (6.35 millimeters [mm]) from the edges of the panel, the identification markings, and the panel holding points during processing or salt spray exposure shall not be evaluated. Differences in color between the test panels and the control panels shall not be cause for rejection." Should panels survive 168 hours and pass the surface resistance test, and test chambers are available, testing will continue until failure, and be evaluated at additional 168 hour intervals. Panels will be evaluated using the following standards.

3.1.3 Test Results – ASTM B 117, 168 hours

Test results following 168 hours of salt spray exposure are provided in Figure 1 through Figure 7 below. Panel photographs are included in Appendix A.

During test panel inspection, it was observed that the control, Alodine 1600, did not perform as expected. Following 168 hours of salt spray exposure, all of the test panels with Alodine 1600 were deemed failed. This unexpected result brings into question the compatibility of Alodine 1600 and the panel preparation procedure selected for this project.

Inspection of the hexavalent chrome free pretreatments revealed a clear trend with respect to pretreatment performance by alloy. Pretreatments on alloys known for their resistance to corrosion (6061-T6 and 5052-H32) showed no evidence of corrosion when compared to unexposed control panels after 168 hours of salt spray exposure. Pretreatments on alloys that are known to have less inherent resistance to corrosion, mostly due to having a higher copper content (2024-T3 and 7075-T73) were determined failed after 168 hours of salt spray exposure. Such a strong delineation of the data across alloy type, regardless of hexavalent chrome free pretreatment, was not expected. This unexpected result once again brings into question the panel preparation procedure selected for this project.

Pretreatment	Alloy	Unique Panel #	Batch #	Family	@ 168 Hours
Alodine 1600	6061-T6	1006	B7	b	Fail
		1007	B6	b	Fail
		1008	B6	b	Fail
		1009	B6	b	Fail
		1010	B1	b	Fail
	7075-T73	1051	B7	b	Fail
		1052	B7	b	Fail
		1053	B4	b	Fail
		1054	B4	b	Fail
		1055	B2	b	Fail
	2024-T3	1089	B1	b	Fail
		1090	B3	b	Fail
		1091	B5	b	Fail
		1092	B3	b	Fail
		1093	B3	b	Fail
	5052-H32	1128	B7	b	Fail
		1129	B6	b	Fail
		1130	B2	b	Fail
		1131	B5	b	Fail
		1132	B2	b	Fail

Figure 1 – ASTM B 117 Results @ 168 Hours; Alodine 1600

Pretreatment	Alloy	Unique Panel #	Batch #	Family	@ 168 Hours
Alodine T 5900 RTU	6061-T6	2006	B7	b	Pass
		2007	B6	b	Pass
		2008	B6	b	Pass
		2009	B6	b	Pass
		2010	B1	b	Pass
	7075-T73	2051	B7	b	Fail
		2052	B7	b	Fail
		2053	B4	b	Fail
		2054	B4	b	Fail
		2055	B2	b	Fail
	2024-T3	2089	B1	b	Fail
		2090	B3	b	Fail
		2091	B5	b	Fail
		2092	B3	b	Fail
		2093	B3	b	Fail
	5052-H32	2128	B7	b	Pass
		2129	B6	b	Pass
		2130	B2	b	Pass
		2131	B5	b	Pass
		2132	B2	b	Pass

Figure 2 - ASTM B 117 Results @ 168 Hours; Alodine T 5900 RTU

Pretreatment	Alloy	Unique Panel #	Batch #	Family	@ 168 Hours
Iridite NCP	6061-T6	3006	B7	b	Pass
		3007	B6	b	Pass
		3008	B6	b	Pass
		3009	B6	b	Pass
		3010	B1	b	Pass
	7075-T73	3051	B7	b	Fail
		3052	B7	b	Fail
		3053	B4	b	Fail
		3054	B4	b	Fail
		3055	B2	b	Fail
	2024-T3	3089	B1	b	Fail
		3090	B3	b	Fail
		3091	B5	b	Fail
		3092	B3	b	Fail
		3093	B3	b	Fail
	5052-H32	3128	B7	b	Pass
		3129	B6	b	Pass
		3130	B2	b	Pass
		3131	B5	b	Pass
		3132	B2	b	Pass

Figure 3 - ASTM B 117 Results @ 168 Hours; Iridite NCP

Pretreatment	Alloy	Unique Panel #	Batch #	Family	@ 168 Hours
Metalast HF	6061-T6	4006	B7	b	Pass
		4007	B6	b	Pass
		4008	B6	b	Pass
		4009	B6	b	Pass
		4010	B1	b	Pass
	7075-T73	4051	B7	b	Fail
		4052	B7	b	Fail
		4053	B4	b	Fail
		4054	B4	b	Fail
		4055	B2	b	Fail
	2024-T3	4089	B1	b	Fail
		4090	B3	b	Fail
		4091	B5	b	Fail
		4092	B3	b	Fail
		4093	B3	b	Fail
	5052-H32	4128	B7	b	Pass
		4129	B6	b	Pass
		4130	B2	b	Pass
		4131	B5	b	Pass
		4132	B2	b	Pass

Figure 4 - ASTM B 117 Results @ 168 Hours; Metalast HF

Pretreatment	Alloy	Unique Panel #	Batch #	Family	@ 168 Hours
Metalast HF-EPA	6061-T6	5006	B7	b	Pass
		5007	B6	b	Pass
		5008	B6	b	Pass
		5009	B6	b	Pass
		5010	B1	b	Pass
	7075-T73	5051	B7	b	Fail
		5052	B7	b	Fail
		5053	B4	b	Fail
		5054	B4	b	Fail
		5055	B2	b	Fail
	2024-T3	5089	B1	b	Fail
		5090	B3	b	Fail
		5091	B5	b	Fail
		5092	B3	b	Fail
		5093	B3	b	Fail
	5052-H32	5128	B7	b	Pass
		5129	B6	b	Pass
		5130	B2	b	Pass
		5131	B5	b	Pass
		5132	B2	b	Pass

Figure 5 - ASTM B 117 Results @ 168 Hours; Metalast HF-EPA

Pretreatment	Alloy	Unique Panel #	Batch #	Family	@ 168 Hours
SurTec 650	6061-T6	6006	B7	b	Pass
		6007	B6	b	Pass
		6008	B6	b	Pass
		6009	B6	b	Pass
		6010	B1	b	Pass
	7075-T73	6051	B7	b	Fail
		6052	B7	b	Fail
		6053	B4	b	Fail
		6054	B4	b	Fail
		6055	B2	b	Fail
	2024-T3	6089	B1	b	Fail
		6090	B3	b	Fail
		6091	B5	b	Fail
		6092	B3	b	Fail
		6093	B3	b	Fail
	5052-H32	6128	B7	b	Pass
		6129	B6	b	Pass
		6130	B2	b	Pass
		6131	B5	b	Pass
		6132	B2	b	Pass

Figure 6 - ASTM B 117 Results @ 168 Hours; SurTec 650

Pretreatment	Alloy	Unique Panel #	Batch #	Family	@ 168 Hours
SurTec 650C	6061-T6	7006	B7	b	Pass
		7007	B6	b	Pass
		7008	B6	b	Pass
		7009	B6	b	Pass
		7010	B1	b	Pass
	7075-T73	7051	B7	b	Fail
		7052	B7	b	Fail
		7053	B4	b	Fail
		7054	B4	b	Fail
		7055	B2	b	Fail
	2024-T3	7089	B1	b	Fail
		7090	B3	b	Fail
		7091	B5	b	Fail
		7092	B3	b	Fail
		7093	B3	b	Fail
	5052-H32	7128	B7	b	Pass
		7129	B6	b	Pass
		7130	B2	b	Pass
		7131	B5	b	Pass
		7132	B2	b	Pass

Figure 7 - ASTM B 117 Results @ 168 Hours; SurTec 650

3.1.4 Test Results – ASTM B 117, to Failure

Test results following 168 hours of salt spray exposure are provided in Figure 8 through Figure 14 below. Panel photographs are included in Appendix B. All five 6061-T6 test panels as well as 1 of 5 test panels for 7075-T73, 2024-T3, and 5052-H32 for all pretreatments were used for surface resistance readings. These panels were prepared at the same time as the other test panels, but were not tested at the same time. Test panels not used for surface resistance measurements were inspected at 168 hour intervals. Test panels that were considered failed were removed from the test chamber prior to continuing the test.

Alodine 1600 did not perform as expected on 7075-T73, 2024-T3 and 5052-H32 test panels. Curiously, Alodine 1600 did perform well on 6061-T6 test panels, a polar result to the ASTM B 117 salt spray results reported in section 3.1.3. Following 168 hours of salt spray exposure, all of the 7075-T73, 2024-T3 test panels with Alodine 1600 were considered failed. For 5052-H32 test panels, nearly all of the test panels failed, 4 of 5, the one exception was the test panel that was used for surface resistance measurements. These results bring into question the compatibility of Alodine 1600 and the panel preparation procedure selected for this project.

The hexavalent chrome free pretreatments on 6061-T6 test panels performed well, with not more than one test panel deemed failed after 168 hours of ASTM B 117 salt spray exposure, for a majority of the pretreatments. Two pretreatments had more than one test panel deemed failed following 168 hours of ASTM B 117 salt spray exposure; Alodine T 5900 RTU and Metalast HF. Pretreatments on 5052-H32 test panels showed no evidence of corrosion when compared to unexposed control panels after 1008 hours of salt spray exposure for a majority of test panels. Noted exception, Metalast HF only had two test panels make the 1008 hour mark. It should also be noted that for Metalast HF the only test panel that did not pass 336 hours of exposure was the test panel used for resistance measurements. Iridite NCP and SurTec 650C has similar anomalies, with the only test panels to fail at 168 hours of exposure was the test panels

used for ASTM D 257 measurements. Hexavalent chrome free pretreatments on alloys that are known to have less inherent resistance to corrosion, mostly due to having a higher copper content (2024-T3 and 7075-T73) were determined failed after 168 hours of salt spray exposure.

For Figure 94, Figure 98, Figure 102, and Figure 110 (all in Appendix B) there are markings associated with the 803B probe used to obtain surface resistance measurements. This is important to note because the purpose of running this test was to determine if it could be utilized as a non-destructive test method for surface resistivity of test panels to allow for readings throughout testing lifecycles. The presence of visible markings due to the 803B probe show that some level of damage is occurring to the coated surface.

Pretreatment	Alloy	Panel #	Batch #	Family	168 Hrs	336 Hrs	504 Hrs	672 Hrs	840 Hrs	1008 Hrs
Alodine 1600	6061-T6	1011*	B1	c	Fail	N/A	N/A	N/A	N/A	N/A
		1012*	B7	c	Pass	N/A	N/A	N/A	N/A	N/A
		1013*	B6	c	Pass	N/A	N/A	N/A	N/A	N/A
		1014*	B4	c	Pass	N/A	N/A	N/A	N/A	N/A
		1015*	B1	c	Pass	N/A	N/A	N/A	N/A	N/A
	7075-T73	1056	B6	c	Fail	N/A	N/A	N/A	N/A	N/A
		1057	B5	c	Fail	N/A	N/A	N/A	N/A	N/A
		1058	B3	c	Fail	N/A	N/A	N/A	N/A	N/A
		1059	B1	c	Fail	N/A	N/A	N/A	N/A	N/A
		1060*	B5	c	Fail	N/A	N/A	N/A	N/A	N/A
	2024-T3	1094	B6	c	Fail	N/A	N/A	N/A	N/A	N/A
		1095	B4	c	Fail	N/A	N/A	N/A	N/A	N/A
		1096	B7	c	Fail	N/A	N/A	N/A	N/A	N/A
		1097	B2	c	Fail	N/A	N/A	N/A	N/A	N/A
		1098*	B3	c	Fail	N/A	N/A	N/A	N/A	N/A
	5052-H32	1133	B2	c	Fail	N/A	N/A	N/A	N/A	N/A
		1134	B5	c	Fail	N/A	N/A	N/A	N/A	N/A
		1135	B5	c	Fail	N/A	N/A	N/A	N/A	N/A
		1136	B7	c	Fail	N/A	N/A	N/A	N/A	N/A
		1137*	B2	c	Pass	N/A	N/A	N/A	N/A	N/A

*Note - Test panels were used for ASTM D 257 analysis before and after ASTM B 117 exposure. Test panels were not tested at the same time as the others listed in the table. Testing was stopped after 168 hours.

Figure 8 - ASTM B 117 Results, To Failure; Alodine 1600

Pretreatment	Alloy	Panel #	Batch #	Family	168 Hrs	336 Hrs	504 Hrs	672 Hrs	840 Hrs	1008 Hrs
Alodine T 5900 RTU	6061-T6	2011*	B1	c	Fail	N/A	N/A	N/A	N/A	N/A
		2012*	B7	c	Pass	N/A	N/A	N/A	N/A	N/A
		2013*	B6	c	Pass	N/A	N/A	N/A	N/A	N/A
		2014*	B4	c	Fail	N/A	N/A	N/A	N/A	N/A
		2015*	B1	c	Pass	N/A	N/A	N/A	N/A	N/A
	7075-T73	2056	B6	c	Fail	N/A	N/A	N/A	N/A	N/A
		2057	B5	c	Fail	N/A	N/A	N/A	N/A	N/A
		2058	B3	c	Fail	N/A	N/A	N/A	N/A	N/A
		2059	B1	c	Fail	N/A	N/A	N/A	N/A	N/A
		2060*	B5	c	Fail	N/A	N/A	N/A	N/A	N/A
	2024-T3	2094	B6	c	Fail	N/A	N/A	N/A	N/A	N/A
		2095	B4	c	Fail	N/A	N/A	N/A	N/A	N/A
		2096	B7	c	Fail	N/A	N/A	N/A	N/A	N/A
		2097	B2	c	Fail	N/A	N/A	N/A	N/A	N/A
		2098*	B3	c	Fail	N/A	N/A	N/A	N/A	N/A
	5052-H32	2133	B2	c	Pass	Pass	Pass	Pass	Pass	Pass
		2134	B5	c	Pass	Pass	Pass	Pass	Pass	Pass
		2135	B5	c	Pass	Pass	Pass	Pass	Pass	Pass
		2136	B7	c	Pass	Pass	Pass	Pass	Pass	Pass
		2137*	B2	c	Pass	N/A	N/A	N/A	N/A	N/A

*Note - Test panels were used for ASTM D 257 analysis before and after ASTM B 117 exposure. Test panels were not tested at the same time as the others listed in the table. Testing was stopped after 168 hours.

Figure 9 - ASTM B 117 Results, To Failure; Alodine T 5900 RTU

Pretreatment	Alloy	Panel #	Batch #	Family	168 Hrs	336 Hrs	504 Hrs	672 Hrs	840 Hrs	1008 Hrs
Iridite NCP	6061-T6	3011*	B1	c	Pass	N/A	N/A	N/A	N/A	N/A
		3012*	B7	c	Pass	N/A	N/A	N/A	N/A	N/A
		3013*	B6	c	Fail	N/A	N/A	N/A	N/A	N/A
		3014*	B4	c	Pass	N/A	N/A	N/A	N/A	N/A
		3015*	B1	c	Pass	N/A	N/A	N/A	N/A	N/A
	7075-T73	3056	B6	c	Fail	N/A	N/A	N/A	N/A	N/A
		3057	B5	c	Fail	N/A	N/A	N/A	N/A	N/A
		3058	B3	c	Fail	N/A	N/A	N/A	N/A	N/A
		3059	B1	c	Fail	N/A	N/A	N/A	N/A	N/A
		3060*	B5	c	Fail	N/A	N/A	N/A	N/A	N/A
	2024-T3	3094	B6	c	Fail	N/A	N/A	N/A	N/A	N/A
		3095	B4	c	Fail	N/A	N/A	N/A	N/A	N/A
		3096	B7	c	Fail	N/A	N/A	N/A	N/A	N/A
		3097	B2	c	Fail	N/A	N/A	N/A	N/A	N/A
		3098*	B3	c	Fail	N/A	N/A	N/A	N/A	N/A
	5052-H32	3133	B2	c	Pass	Pass	Pass	Pass	Pass	Pass
		3134	B5	c	Pass	Pass	Pass	Pass	Pass	Pass
		3135	B5	c	Pass	Pass	Pass	Pass	Pass	Pass
		3136	B7	c	Pass	Pass	Pass	Pass	Pass	Pass
		3137*	B2	c	Fail	N/A	N/A	N/A	N/A	N/A

*Note - Test panels were used for ASTM D 257 analysis before and after ASTM B 117 exposure. Test panels were not tested at the same time as the others listed in the table. Testing was stopped after 168 hours.

Figure 10 - ASTM B 117 Results, To Failure; Iridite NCP

Pretreatment	Alloy	Panel #	Batch #	Family	168 Hrs	336 Hrs	504 Hrs	672 Hrs	840 Hrs	1008 Hrs
Metalast HF	6061-T6	4011*	B1	c	Fail	N/A	N/A	N/A	N/A	N/A
		4012*	B7	c	Fail	N/A	N/A	N/A	N/A	N/A
		4013*	B6	c	Fail	N/A	N/A	N/A	N/A	N/A
		4014*	B4	c	Fail	N/A	N/A	N/A	N/A	N/A
		4015*	B1	c	Pass	N/A	N/A	N/A	N/A	N/A
	7075-T73	4056	B6	c	Fail	N/A	N/A	N/A	N/A	N/A
		4057	B5	c	Fail	N/A	N/A	N/A	N/A	N/A
		4058	B3	c	Fail	N/A	N/A	N/A	N/A	N/A
		4059	B1	c	Fail	N/A	N/A	N/A	N/A	N/A
		4060*	B5	c	Fail	N/A	N/A	N/A	N/A	N/A
	2024-T3	4094	B6	c	Fail	N/A	N/A	N/A	N/A	N/A
		4095	B4	c	Fail	N/A	N/A	N/A	N/A	N/A
		4096	B7	c	Fail	N/A	N/A	N/A	N/A	N/A
		4097	B2	c	Fail	N/A	N/A	N/A	N/A	N/A
		4098*	B3	c	Fail	N/A	N/A	N/A	N/A	N/A
	5052-H32	4133	B2	c	Pass	Pass	Fail	N/A	N/A	N/A
		4134	B5	c	Pass	Pass	Pass	Fail	N/A	N/A
		4135	B5	c	Pass	Pass	Pass	Pass	Pass	Pass
		4136	B7	c	Pass	Pass	Pass	Pass	Pass	Pass
		4137*	B2	c	Fail	N/A	N/A	N/A	N/A	N/A

*Note - Test panels were used for ASTM D 257 analysis before and after ASTM B 117 exposure. Test panels were not tested at the same time as the others listed in the table. Testing was stopped after 168 hours.

Figure 11 - ASTM B 117 Results, To Failure; Metalast HF

Pretreatment	Alloy	Panel #	Batch #	Family	168 Hrs	336 Hrs	504 Hrs	672 Hrs	840 Hrs	1008 Hrs
Metalast HF-EPA	6061-T6	5011*	B1	c	Pass	N/A	N/A	N/A	N/A	N/A
		5012*	B7	c	Fail	N/A	N/A	N/A	N/A	N/A
		5013*	B6	c	Pass	N/A	N/A	N/A	N/A	N/A
		5014*	B4	c	Pass	N/A	N/A	N/A	N/A	N/A
		5015*	B1	c	Pass	N/A	N/A	N/A	N/A	N/A
	7075-T73	5056	B6	c	Fail	N/A	N/A	N/A	N/A	N/A
		5057	B5	c	Fail	N/A	N/A	N/A	N/A	N/A
		5058	B3	c	Fail	N/A	N/A	N/A	N/A	N/A
		5059	B1	c	Fail	N/A	N/A	N/A	N/A	N/A
		5060*	B5	c	Fail	N/A	N/A	N/A	N/A	N/A
	2024-T3	5094	B6	c	Fail	N/A	N/A	N/A	N/A	N/A
		5095	B4	c	Fail	N/A	N/A	N/A	N/A	N/A
		5096	B7	c	Fail	N/A	N/A	N/A	N/A	N/A
		5097	B2	c	Fail	N/A	N/A	N/A	N/A	N/A
		5098*	B3	c	Fail	N/A	N/A	N/A	N/A	N/A
	5052-H32	5133	B2	c	Pass	Pass	Pass	Pass	Pass	Pass
		5134	B5	c	Pass	Pass	Pass	Pass	Pass	Pass
		5135	B5	c	Pass	Pass	Pass	Pass	Pass	Pass
		5136	B7	c	Pass	Pass	Pass	Pass	Pass	Pass
		5137*	B2	c	Pass	N/A	N/A	N/A	N/A	N/A

*Note - Test panels were used for ASTM D 257 analysis before and after ASTM B 117 exposure. Test panels were not tested at the same time as the others listed in the table. Testing was stopped after 168 hours.

Figure 12 - ASTM B 117 Results, To Failure; Metalast HF-EPA

Pretreatment	Alloy	Panel #	Batch #	Family	168 Hrs	336 Hrs	504 Hrs	672 Hrs	840 Hrs	1008 Hrs
SurTec 650	6061-T6	6011*	B1	c	Pass	N/A	N/A	N/A	N/A	N/A
		6012*	B7	c	Fail	N/A	N/A	N/A	N/A	N/A
		6013*	B6	c	Pass	N/A	N/A	N/A	N/A	N/A
		6014*	B4	c	Pass	N/A	N/A	N/A	N/A	N/A
		6015*	B1	c	Pass	N/A	N/A	N/A	N/A	N/A
	7075-T73	6056	B6	c	Fail	N/A	N/A	N/A	N/A	N/A
		6057	B5	c	Fail	N/A	N/A	N/A	N/A	N/A
		6058	B3	c	Fail	N/A	N/A	N/A	N/A	N/A
		6059	B1	c	Fail	N/A	N/A	N/A	N/A	N/A
		6060*	B5	c	Fail	N/A	N/A	N/A	N/A	N/A
	2024-T3	6094	B6	c	Fail	N/A	N/A	N/A	N/A	N/A
		6095	B4	c	Fail	N/A	N/A	N/A	N/A	N/A
		6096	B7	c	Fail	N/A	N/A	N/A	N/A	N/A
		6097	B2	c	Fail	N/A	N/A	N/A	N/A	N/A
		6098*	B3	c	Pass	N/A	N/A	N/A	N/A	N/A
	5052-H32	6133	B2	c	Pass	Pass	Pass	Pass	Pass	Pass
		6134	B5	c	Pass	Pass	Pass	Pass	Pass	Pass
		6135	B5	c	Pass	Pass	Pass	Pass	Pass	Pass
		6136	B7	c	Pass	Pass	Pass	Pass	Pass	Pass
		6137*	B2	c	Pass	N/A	N/A	N/A	N/A	N/A

*Note - Test panels were used for ASTM D 257 analysis before and after ASTM B 117 exposure. Test panels were not tested at the same time as the others listed in the table. Testing was stopped after 168 hours.

Figure 13 - ASTM B 117 Results, To Failure; SurTec 650

Pretreatment	Alloy	Panel #	Batch #	Family	168 Hrs	336 Hrs	504 Hrs	672 Hrs	840 Hrs	1008 Hrs
SurTec 650C	6061-T6	7011*	B1	c	Pass	N/A	N/A	N/A	N/A	N/A
		7012*	B7	c	Pass	N/A	N/A	N/A	N/A	N/A
		7013*	B6	c	Fail	N/A	N/A	N/A	N/A	N/A
		7014*	B4	c	Pass	N/A	N/A	N/A	N/A	N/A
		7015*	B1	c	Pass	N/A	N/A	N/A	N/A	N/A
	7075-T73	7056	B6	c	Fail	N/A	N/A	N/A	N/A	N/A
		7057	B5	c	Fail	N/A	N/A	N/A	N/A	N/A
		7058	B3	c	Fail	N/A	N/A	N/A	N/A	N/A
		7059	B1	c	Fail	N/A	N/A	N/A	N/A	N/A
		7060*	B5	c	Fail	N/A	N/A	N/A	N/A	N/A
	2024-T3	7094	B6	c	Fail	N/A	N/A	N/A	N/A	N/A
		7095	B4	c	Fail	N/A	N/A	N/A	N/A	N/A
		7096	B7	c	Fail	N/A	N/A	N/A	N/A	N/A
		7097	B2	c	Fail	N/A	N/A	N/A	N/A	N/A
		7098*	B3	c	Fail	N/A	N/A	N/A	N/A	N/A
	5052-H32	7133	B2	c	Pass	Pass	Pass	Pass	Pass	Pass
		7134	B5	c	Pass	Pass	Pass	Pass	Pass	Pass
		7135	B5	c	Pass	Pass	Pass	Pass	Pass	Pass
		7136	B7	c	Pass	Pass	Pass	Pass	Pass	Pass
		7137*	B2	c	Fail	N/A	N/A	N/A	N/A	N/A

*Note - Test panels were used for ASTM D 257 analysis before and after ASTM B 117 exposure. Test panels were not tested at the same time as the others listed in the table. Testing was stopped after 168 hours.

Figure 14 - ASTM B 117 Results, To Failure; SurTec 650C

3.2 Cyclic Corrosion

This test evaluates the corrosion protection that coatings provide on metal samples in an accelerated corrosive environment. Cyclic corrosion testing is necessary to determine the effects of a marine environment on the coating system.

3.2.1 Test Procedure

Three (3) replicates per substrate / per coating underwent cyclic corrosion testing in accordance with ASTM G 85 (Modified Salt Spray (Fog) Testing), Annex 5 (dilute electrolyte cyclic fog dry test) for duration of 7 days (1 week {168 hours}). All of the samples were exposed to a salt fog solution consisting of 0.05% sodium chloride (NaCl) and 0.35% ammonium sulfate by weight for approximately one hour at ambient temperature (approximately 75°F), followed by approximately one hour of drying at approximately 95°F.

3.2.2 Evaluation Procedure

For this effort, the following criteria were used when evaluating the test panels; MIL-DTL-81706B, section 3.5.1; "the specimens shall show no evidence of corrosion when compared to unexposed control panels using the naked eye. Areas within 0.25 inch (6.35 millimeters [mm]) from the edges of the panel, the identification markings, and the panel holding points during processing or salt spray exposure shall not be evaluated. Differences in color between the test panels and the control panels shall not be cause for rejection."

3.2.3 Test Results – ASTM G 85 Annex 5, 168 hours

Test results following 168 hours of cyclic corrosion testing are provided in Figure 15 through Figure 21 below. Panel photographs are included in Appendix C.

Following 168 hours of cyclic corrosion testing, test panels with Alodine 1600 revealed a clear trend with respect to pretreatment performance by alloy. As mentioned in the ASTM B 117 test result sections, Alodine 1600 on alloys known for their resistance to corrosion (6061-T6 and 5052-H32) showed no evidence of corrosion when compared to unexposed control panels after 168 hours of cyclic corrosion testing. Alodine 1600 on alloys that are known to have less inherent resistance to corrosion, mostly due to having a higher copper content (2024-T3 and 7075-T73) were determined failed after 168 hours of salt spray exposure.

Inspection of the hexavalent chrome free pretreatments once again revealed a clear trend with respect to pretreatment performance by alloy. As mentioned in the ASTM B 117 test results sections, pretreatments on alloys known for their resistance to corrosion (6061-T6 and 5052-H32) showed no evidence of corrosion when compared to unexposed control panels after 168 hours of cyclic corrosion testing. There was one exception to the trend; Metalast HF did show signs of corrosion 6061-T6 and 5052-H32 alloys. Pretreatments on alloys that are known to have less inherent resistance to corrosion, mostly due to having a higher copper content (2024-T3 and 7075-T73) were determined failed after 168 hours of salt spray exposure.

Pretreatment	Alloy	Unique Panel #	Batch #	Family	Result @ 168 Hours
Alodine 1600	6061-T6	1017	B1	d	Pass
		1018	B3	d	Pass
		1019	B7	d	Pass
	7075-T73	1062	B3	d	Fail
		1063	B6	d	Fail
		1064	B4	d	Fail
	2024-T3	1100	B1	d	Fail
		1101	B6	d	Fail
		1102	B3	d	Fail
	5052-H32	1139	B2	d	Pass
		1140	B6	d	Pass
		1141	B7	d	Pass

Figure 15 - ASTM G 85, Annex 5 Results, 168 Hours; Alodine 1600

Pretreatment	Alloy	Unique Panel #	Batch #	Family	Result @ 168 Hours
Alodine T 5900 RTU	6061-T6	2017	B1	d	Pass
		2018	B3	d	Pass
		2019	B7	d	Pass
	7075-T73	2062	B3	d	Fail
		2063	B6	d	Fail
		2064	B4	d	Fail
	2024-T3	2100	B1	d	Fail
		2101	B6	d	Fail
		2102	B3	d	Fail
	5052-H32	2139	B2	d	Pass
		2140	B6	d	Pass
		2141	B7	d	Pass

Figure 16 - ASTM G 85, Annex 5 Results, 168 Hours; Alodine T 5900 RTU

Pretreatment	Alloy	Unique Panel #	Batch #	Family	Result @ 168 Hours
Iridite NCP	6061-T6	3017	B1	d	Pass
		3018	B3	d	Pass
		3019	B7	d	Pass
	7075-T73	3062	B3	d	Fail
		3063	B6	d	Fail
		3064	B4	d	Fail
	2024-T3	3100	B1	d	Fail
		3101	B6	d	Fail
		3102	B3	d	Fail
	5052-H32	3139	B2	d	Pass
		3140	B6	d	Pass
		3141	B7	d	Pass

Figure 17 - ASTM G 85, Annex 5 Results, 168 Hours; Iridite NCP

Pretreatment	Alloy	Unique Panel #	Batch #	Family	Result @ 168 Hours
Metalast HF	6061-T6	4017	B1	d	Fail
		4018	B3	d	Fail
		4019	B7	d	Fail
	7075-T73	4062	B3	d	Fail
		4063	B6	d	Fail
		4064	B4	d	Fail
	2024-T3	4100	B1	d	Fail
		4101	B6	d	Fail
		4102	B3	d	Fail
	5052-H32	4139	B2	d	Fail
		4140	B6	d	Fail
		4141	B7	d	Fail

Figure 18 - ASTM G 85, Annex 5 Results, 168 Hours; Metalast HF

Pretreatment	Alloy	Unique Panel #	Batch #	Family	Result @ 168 Hours
Metalast HF-EPA	6061-T6	5016	B1	d	Pass
		5018	B3	d	Pass
		5019	B7	d	Pass
	7075-T73	5062	B3	d	Fail
		5063	B6	d	Fail
		5064	B4	d	Fail
	2024-T3	5100	B1	d	Fail
		5101	B6	d	Fail
		5102	B3	d	Fail
	5052-H32	5139	B2	d	Pass
		5140	B6	d	Pass
		5141	B7	d	Pass

Figure 19 - ASTM G 85, Annex 5 Results, 168 Hours; Metalast HF-EPA

Pretreatment	Alloy	Unique Panel #	Batch #	Family	Result @ 168 Hours
SurTec 650	6061-T6	6017	B1	d	Pass
		6018	B3	d	Pass
		6019	B7	d	Pass
	7075-T73	6062	B3	d	Fail
		6063	B6	d	Fail
		6064	B4	d	Fail
	2024-T3	6100	B1	d	Fail
		6101	B6	d	Fail
		6102	B3	d	Fail
	5052-H32	6139	B2	d	Pass
		6140	B6	d	Pass
		6141	B7	d	Pass

Figure 20 - ASTM G 85, Annex 5 Results, 168 Hours; SurTec 650

Pretreatment	Alloy	Unique Panel #	Batch #	Family	Result @ 168 Hours
SurTec 650C	6061-T6	7017	B1	d	Pass
		7018	B3	d	Pass
		7019	B7	d	Pass
	7075-T73	7062	B3	d	Fail
		7063	B6	d	Fail
		7064	B4	d	Fail
	2024-T3	7100	B1	d	Fail
		7101	B6	d	Fail
		7102	B3	d	Fail
	5052-H32	7139	B2	d	Pass
		7140	B6	d	Pass
		7141	B7	d	Pass

Figure 21 - ASTM G 85, Annex 5 Results, 168 Hours; SurTec 650C

3.3 Marine Environment

This test evaluates the performance of the test and control coatings during an 18 month outdoor exposure in a marine environment. Accelerated testing is useful for comparing the performance of coatings under accelerated conditions however correlations to actual service performance has been difficult due to different corrosion mechanisms prevalent in the two situations. Therefore, outdoor exposure in the environment of performance is a critical test necessary to determine the effect actual weather patterns and real-world exposure has on the coatings of interest. Comparing data collected from atmospheric and accelerated testing will give insight into anticipated performance of a coating system before being field tested.

3.3.1 Test Procedure

Atmospheric exposure testing will follow ASTM D 1014 (Standard Practice for Conducting Exterior Exposure Tests of Paints and Coatings on Metal Substrates).

Three (3) replicates per substrate / per coating were installed at the KSC outdoor exposure facility, located at latitude 28.594°N, longitude -80.582°W, and approximately 100 feet (30 meters) from the high tide line. Testing followed KSC testing procedures for fasteners, exposure angle, and inspection intervals unless otherwise noted. Comparing data collected from atmospheric and accelerated testing will give insight into anticipated performance of a coating system before being field tested.

3.3.2 Evaluation Procedure

Test panels were evaluated and photographed weekly for five (5) weeks. After 5 weeks of exposure, the test panels were removed from the beach and evaluated as follows; MIL-DTL-81706B, section 3.5.1;"the specimens shall show no evidence of corrosion when compared to unexposed control panels using the naked eye. Areas within 0.25 inch (6.35 millimeters [mm]) from the edges of the panel, the identification markings, and the panel holding points during processing or salt spray exposure shall not be evaluated. Differences in color between the test panels and the control panels shall not be cause for rejection."

3.3.3 Test Results – Beachside Corrosion, 5 Weeks

Following 5 weeks of atmospheric exposure, all test panels showed signs of pitting through the entire test panel regardless of pretreatment or alloy. Overall the pitting was fairly consistent across all test panels

with numerous small pits throughout the test panels. Rack photographs on Day 1 are included in Appendix D, and panel photographs after 5-weeks are included in Appendix E.

3.4 PATTI JR Pull Test

This test evaluates the pull-off strength (commonly referred to as adhesion) of a coating system from metal substrates.

3.4.1 Test Procedure

This test was conducted per ASTM D 4541 (Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers, approved February 1, 2009); Annex 3, Self-Alignment Adhesion Tester Type IV (Test Method D).

Two (2) panels per substrate (6061-T6 and 5052-H32) / per pretreatment were finished with one coat of a volatile organic compound (VOC) compliant epoxy-polyamide primer to a dry film thickness of 0.0006 to 0.0009 inch (0.6 to 0.9 mil). One panel was finished with one coat of epoxy primer conforming to MIL-PRF-23377 (PPG CA7233) while the other was finished with one coat of epoxy primer conforming to MIL-PRF-85582 (Deft 44-GN-07A). Panels were allowed to dry in accordance with the primer specification.

An Elcometer 110 PATTI portable pneumatic adhesion tester was used during testing in conjunction with an F-4 piston and 0.5" pull-stub.

Only hexavalent chrome free pretreatments on alloys 6061-T6 and 5052-H32 were evaluated during this test. Due to the unexpected poor performance of Alodine 1600 during salt spray and cyclic corrosion testing, none of the Alodine 1600 test panels were submitted to pull-off strength adhesion testing for cost saving purposes. Hexavalent chrome free pretreatments on alloys 2024-T3 and 7075-T73 were also omitted from pull-off strength adhesion testing due to unexpected poor performance during salt spray and cyclic corrosion testing.

3.4.2 Evaluation Procedure

This is a qualitative test performed in order to determine adhesion (both inner-coat adhesion and intra-coat cohesion) of coating systems. This test is a measure of the direct normal applied force required to remove one or more layers from a coating system as a measure of adhesion strength.

The stakeholders of the Hex Chrome Free Coatings for Electronics Applications project did not set pass / fail criteria for this test.

3.4.3 Test Results – PATTI JR Pull Test

Test results from PATTI JR Pull Testing are contained in Figure 22 and Figure 23. Photographs are included in Appendix F. Primer thicknesses for the PPG CA7233 primer were thicker than specified per MIL-PRF-23377. Primer thicknesses for the Deft 44-GN-07A primer met specification or were slightly thicker than specified per MIL-PRF-85582. For the PPG CA7233 primer, the high occurrence of adhesive failures at the primer / substrate interface may be attributed to the primer being inadvertently thicker after application than specified in MIL-PRF-23377. Test results from the Deft 44-GN-07A coated panels show a high occurrence of failures attributed to bad adhesive. This may be attributed to a pot life issue with the adhesive.

Pretreatment	Alloy	Primer	Primer Thickiness	Panel #	Pull-Off Tensile Strength (POTS) (psi)			Average (psi)
Alodine T 5900 RTU	6061-T6	PPG CA7233	1.9	2029	399	401	381	394
	Fracture Mode				100% adhesive primer/substrate	100% adhesive primer/substrate	100% adhesive primer/substrate	
	5052-H32	PPG CA7233	1.7	2151	399	428	416	414
	Fracture Mode				100% adhesive primer/substrate	100% adhesive primer/substrate	100% adhesive primer/substrate	
Iridite NCP	6061-T6	PPG CA7233	1.8	3029	436	470	449	452
	Fracture Mode				100% adhesive primer/substrate	100% adhesive primer/substrate	100% adhesive primer/substrate	
	5052-H32	PPG CA7233	1.9	3151	428	436	410	425
	Fracture Mode				100% adhesive primer/substrate	100% adhesive primer/substrate	100% adhesive primer/substrate	
Metalast HF	6061-T6	PPG CA7233	1.7	4029	560	569	560	563
	Fracture Mode				85% adhesive primer/substrate 15% bad adhesive	85% adhesive primer/substrate 15% bad adhesive	85% adhesive primer/substrate 15% bad adhesive	
	5052-H32	PPG CA7233	1.8	4151	544	523	517	528
	Fracture Mode				85% adhesive primer/substrate 15% bad adhesive	90% adhesive primer/substrate 10% bad adhesive	90% adhesive primer/substrate 10% bad adhesive	
Metalast HF-EPA	6061-T6	PPG CA7233	1.9	5029	391	418	360	390
	Fracture Mode				100% adhesive primer/substrate	100% adhesive primer/substrate	100% adhesive primer/substrate	
	5052-H32	PPG CA7233	2	5151	393	443	230	355
	Fracture Mode				100% adhesive primer/substrate	70% adhesive primer/substrate 30% bad adhesive	100% adhesive primer/substrate	
SurTec 650	6061-T6	PPG CA7233	1.5	6029	467	441	453	454
	Fracture Mode				100% adhesive primer/substrate	100% adhesive primer/substrate	100% adhesive primer/substrate	
	5052-H32	PPG CA7233	1.8	6151	436	426	436	433
	Fracture Mode				100% adhesive primer/substrate	100% adhesive primer/substrate	100% adhesive primer/substrate	
SurTec 650C	6061-T6	PPG CA7233	2	7029	449	445	428	441
	Fracture Mode				100% adhesive primer/substrate	100% adhesive primer/substrate	100% adhesive primer/substrate	
	5052-H32	PPG CA7233	2.3	7151	447	428	401	425
	Fracture Mode				100% adhesive primer/substrate	100% adhesive primer/substrate	100% adhesive primer/substrate	

Figure 22 - PATTI JR Pull Test Results; Primer (MIL-PRF-23377) - PPG CA7233

Pretreatment	Alloy	Primer	Primer Thickiness	Panel #	Pull-Off Tensile Strength (POTS) (psi)			Average (psi)
Alodine T 5900 RTU	6061-T6	Deft 44-GN-07A	0.96	2030	298	306	362	322
				Fracture Mode	100% cohesive primer	100% cohesive primer	85% cohesive primer 15% adhesive primer/substrate	
	5052-H32	Deft 44-GN-07A	0.78	2152	300	350	372	341
				Fracture Mode	100% cohesive primer	100% cohesive primer	100% cohesive primer	
Iridite NCP	6061-T6	Deft 44-GN-07A	1	3030	215	269	346	277
				Fracture Mode	10% cohesive primer 90% bad adhesive	30% cohesive primer 70% bad adhesive	100% bad adhesive	
	5052-H32	Deft 44-GN-07A	1	3152	271	228	259	253
				Fracture Mode	45% cohesive primer 55% bad adhesive	35% cohesive primer 65% bad adhesive	20% cohesive primer 80% bad adhesive	
Metalast HF	6061-T6	Deft 44-GN-07A	1	4030	292	372	275	313
				Fracture Mode	100% cohesive primer	100% cohesive primer	90% cohesive primer 10% bad adhesive	
	5052-H32	Deft 44-GN-07A	0.8	4152	329	288	277	298
				Fracture Mode	100% cohesive primer	75% cohesive primer 25% bad adhesive	100% cohesive primer	
Metalast HF-EPA	6061-T6	Deft 44-GN-07A	1.1	5030	286	385	286	319
				Fracture Mode	10% cohesive primer 90% bad adhesive	100% cohesive primer	50% cohesive primer 50% bad adhesive	
	5052-H32	Deft 44-GN-07A	1.3	5152	393	313	389	365
				Fracture Mode	100% cohesive primer	80% cohesive primer 20% bad adhesive	85% cohesive primer 15% bad adhesive	
SurTec 650	6061-T6	Deft 44-GN-07A	1.1	6030	197	222	240	220
				Fracture Mode	100% bad adhesive	85% cohesive primer 15% bad adhesive	100% bad adhesive	
	5052-H32	Deft 44-GN-07A	1.3	6152	352	310	453	372
				Fracture Mode	100% cohesive primer	100% cohesive primer	95% cohesive primer 5% bad adhesive	
SurTec 650C	6061-T6	Deft 44-GN-07A	1.38	7030	352	354	337	348
				Fracture Mode	100% cohesive primer	100% cohesive primer	100% cohesive primer	
	5052-H32	Deft 44-GN-07A	1.1	7152	381	348	389	372
				Fracture Mode	100% cohesive primer	100% cohesive primer	100% cohesive primer	

Figure 23 - PATTI JR Pull Test Results; Primer (MIL-PRF-85582) - Deft 44-GN-07A

3.5 Cross-Cut Tape Test

This test is used for assessing the adhesion of coating films to metallic substrates by applying and removing pressure-sensitive tape over cuts made in the film.

3.5.1 Test Procedure

The panels were tested in accordance with ASTM D 3359 (Standard Test Methods for Measuring Adhesion by Tape Test), Test Method B, Cross-Cut Tape Test.

Two (2) panels per substrate / per pretreatment were finished with one coat of a volatile organic compound (VOC) compliant epoxy-polyamide primer conforming to MIL PRF 23377 and MIL PRF 85582 (for a total of four panels per substrate) to a dry film thickness of 0.0006 to 0.0009 inch (0.6 to 0.9 mil). A polyurethane topcoat conforming to MIL PRF 85285 (PPG CA9311) was applied.

Per ASTM D 3359, Test Method B, a lattice pattern was made in each direction in the coatings to the substrate. Pressure-sensitive tape was applied over the lattice and then removed, and adhesion is evaluated.

An Elcometer 107 cross hatch cutter was used in conjunction with Elcometer adhesive tape.

Only hexavalent chrome free pretreatments on alloys 6061-T6 and 5052-H32 were evaluated during this test. Due to the unexpected poor performance of Alodine 1600 during salt spray and cyclic corrosion testing, none of the Alodine 1600 test panels were submitted to cross-cut tape testing for cost saving purposes. Hexavalent chrome free pretreatments on alloys 2024-T3 and 7075-T73 were also omitted from cross-cut tape testing due to unexpected poor performance during salt spray and cyclic corrosion testing.

3.5.2 Evaluation Procedure

Panels were evaluated per ASTM D 3359, Test Method B, Figure 1 Classification of Adhesion Test Results (see Figure 24).

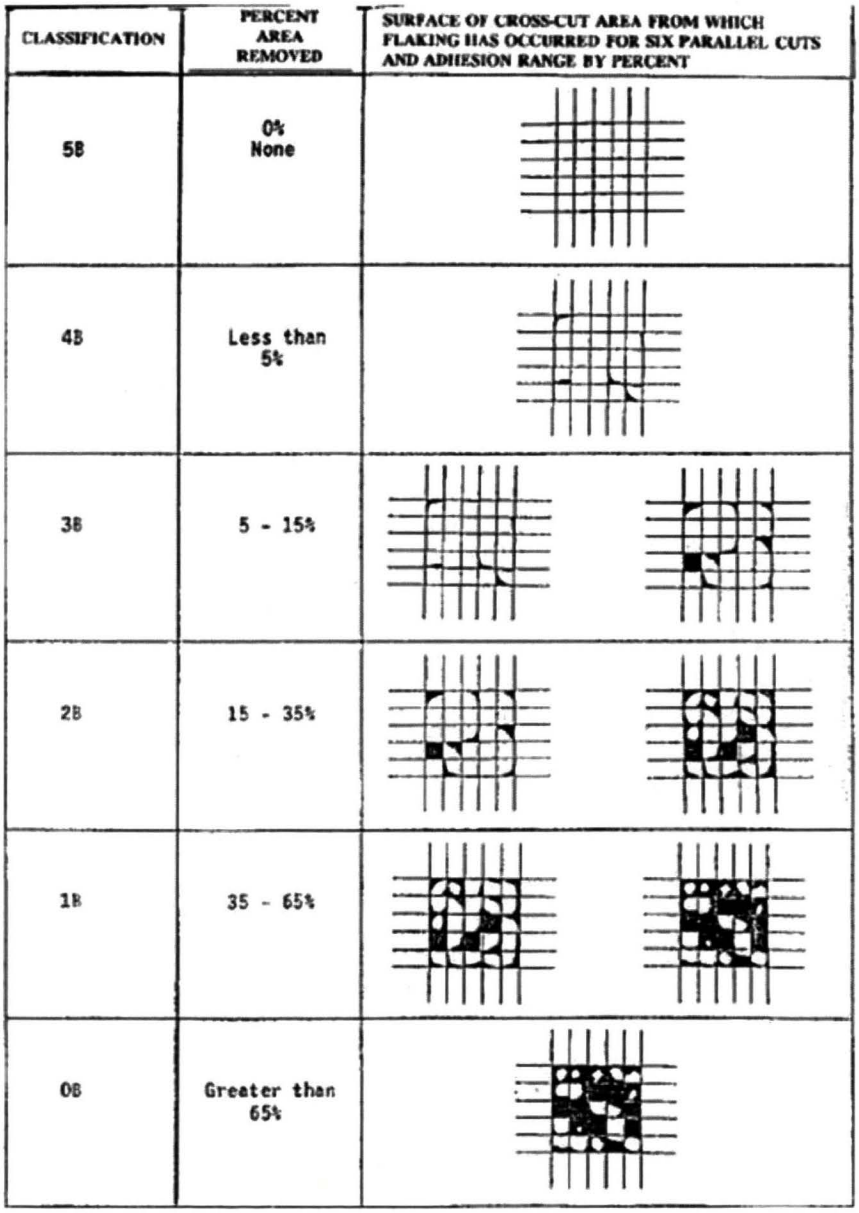

Figure 24 - ASTM D 3359, Test Method B, Figure 1 Classification of Adhesion Test Results

3.5.3 Test Results – Cross-Cut Tape Test

Test results from the Cross-Cut Tape Testing are contained in Figure 25 and Figure 26. Photographs are included in Appendix G. Test panels with PPG CA 7233 primer rated poorly for most of the pretreatments. Only one set of test panels, Metalast HF with PPG CA 7233 primer, received perfect ratings for all test panels analyzed. Iridite NCP with PPG CA 7233 performed adequately on the 5052-H32 test panels. Ratings for Iridite NCP with PPG CA 7233 on 6061-T6 test panels were mixed with one test panel receiving a flawless rating while the other test panel rated below acceptable criteria. Test panels with Deft 44-GN-07A primer were rated as flawless across all test panels regardless of pretreatment or alloy combination. The diversity of results between the two primers may be attributed to the fact that the PPG CA 7233 was thicker than specified in the specifications for this testing after it was applied. It is recommended to consider re-testing with that primer applied more consistently with the specification.

Pretreatment	Alloy	Unique Panel #	Batch #	Result
Alodine T 5900 RTU	6061-T6	2031	B4	1B
		2032	B3	1B
	5052-H32	2153	B7	1B
		2154	B7	1B
Iridite NCP	6061-T6	3031	B4	5B
		3032	B3	2B
	5052-H32	3153	B7	4B
		3154	B7	5B
Metalast HF	6061-T6	4031	B4	5B
		4032	B3	5B
	5052-H32	4153	B7	5B
		4154	B7	5B
Metalast HF-EPA	6061-T6	5031	B4	1B
		5032	B3	1B
	5052-H32	5153	B7	1B
		5154	B7	1B
SurTec 650	6061-T6	6031	B4	2B
		6032	B3	1B
	5052-H32	6153	B7	1B
		6154	B7	1B
SurTec 650C	6061-T6	7031	B4	2B
		7032	B3	2B
	5052-H32	7153	B7	2B
		7154	B7	2B

Figure 25 – Cross-Cut Tape Test Results; Primer (MIL-PRF-23377) - PPG CA7233

Pretreatment	Alloy	Unique Panel #	Batch #	Result
Alodine T 5900 RTU	6061-T6	2033	B2	5B
		2034	B7	5B
	5052-H32	2155	B5	5B
		2156	B2	5B
Iridite NCP	6061-T6	3033	B2	5B
		3034	B7	5B
	5052-H32	3155	B5	5B
		3156	B2	5B
Metalast HF	6061-T6	4033	B2	5B
		4034	B7	5B
	5052-H32	4155	B5	5B
		4156	B2	5B
Metalast HF-EPA	6061-T6	5033	B2	5B
		5034	B7	5B
	5052-H32	5155	B5	5B
		5156	B2	5B
SurTec 650	6061-T6	6033	B2	5B
		6034	B7	5B
	5052-H32	6155	B5	4B
		6156	B2	5B
SurTec 650C	6061-T6	7033	B2	5B
		7034	B7	5B
	5052-H32	7155	B5	5B
		7156	B2	5B

Figure 26 – Cross-Cut Tape Test Results; Primer (MIL-PRF-85582) - Deft 44-GN-07A

3.6 Wet Tape Paint Adhesion

This test evaluates intercoat and surface adhesion of coating systems immersed in water.

3.6.1 Test Procedure

Panels were tested for paint adhesion in accordance with FED-STD-141 (Paint, Varnish, Lacquer and Related Materials: Methods of Inspection, Sampling and Testing), Method 6301.3 (Adhesion (Wet) Tape Test).

Two (2) panels per substrate / per pretreatment shall each be finished with one coat of a volatile organic compound (VOC) compliant epoxy-polyamide primer to a dry film thickness of 0.0006 to 0.0009 inch (0.6 to 0.9 mil). One was finished with one coat of epoxy primer conforming to MIL PRF 23377 (PPG

CA7233) while the other was finished with one coat of epoxy primer conforming to MIL PRF 85582 (Deft 44-GN-07A). All other panels shall be allowed to dry in accordance with the primer specification.

Two immersion procedures were used for this test.

- Test panels immersed in distilled water for 24 hours
- Test panels immersed in distilled water for 96 hours at 120°F

Since a test panel size of 3"x5" is adequate for testing, the original 3"x10" test panels were sheared in half to accommodate two immersion procedures.

Once the test panels were removed from the water and dried, the test panels were scribed with two parallel scratches one inch apart with an x-cut through the middle of the parallel lines (see Figure 27). Immediately after scribing, a 1-inch wide strip of tape (the same Elcometer adhesive tape used for cross-cut tape test) is applied with the adhesive side down across the scratches. The tape was firmly pressed against the surface of the coating; a roller was used to ensure good adhesion. The tape was removed with one quick motion.

Only hexavalent chrome free pretreatments on alloys 6061-T6 and 5052-H32 were evaluated during this test. Due to the unexpected poor performance of Alodine 1600 during salt spray and cyclic corrosion testing, none of the Alodine 1600 test panels were submitted to wet tape adhesion testing for cost saving purposes. Hexavalent chrome free pretreatments on alloys 2024-T3 and 7075-T73 were also omitted from wet tape adhesion testing due to unexpected poor performance during salt spray and cyclic corrosion testing.

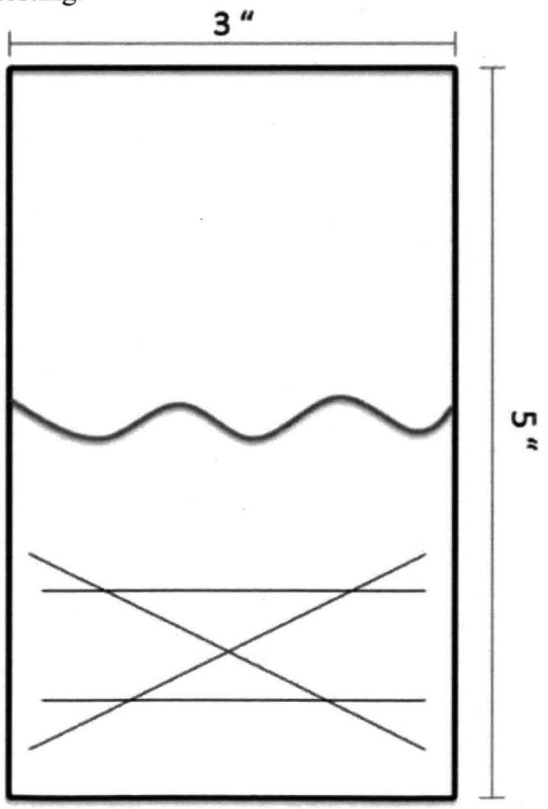

Figure 27 – Wet Tape Adhesion Test Panel

3.6.2 Evaluation Procedure

Panels were evaluated per ASTM D 3359, Test Method A, X-Cut Tape Test per the following criteria:

- 5A No peeling or removal
- 4A Trace peeling or removal along incisions or at their intersection
- 3A Jagged removal along incisions up to 1.6 mm (1/16 in.) on either side
- 2A Jagged removal along most of incisions up to 3.2 mm (1/8 in.) on either side
- 1A Removal from most of the area of the X under the tape
- 0A Removal beyond the area of the X

3.6.3 Test Results – Wet Tape Adhesion, 24 Hour Immersion

Test results from wet tape adhesion testing, 24 hour immersion, are contained in Figure 28 and Figure 29. Photographs are included in Appendix H. Test panels with PPG CA7233 primer had acceptable ratings (4A or better) for most of the hexavalent chrome free pretreatments on 5052-H32 and 6061-T6 test panels. Only Metalast HF-EPA with PPG CA7233 primer rated below 4A on 5052-H32 and 6061-T6 test panels. Results for Alodine T 5900 RTU with PPG CA7233 primer were mixed; a perfect rating was recorded for the 5052-H32 test panel while a failing rating of 3A was recorded for the 6061-T6 test panel. Test panels with Deft 44-GN-07A primer were rated as flawless across all test panels regardless of pretreatment or alloy combination. See the comment in section 3.5.3 regarding coating thickness of PPG CA7233.

Pretreatment	Alloy	Panel #	Evaluation
Alodine T 5900 RTU	6061-T6	2035	3A
	5052-H32	2157	5A
Iridite NCP	6061-T6	3035	5A
	5052-H32	3157	5A
Metalast HF	6061-T6	4035	5A
	5052-H32	4157	5A
Metalast HF-EPA	6061-T6	5035	3A
	5052-H32	5157	3A
SurTec 650	6061-T6	6035	5A
	5052-H32	6157	4A
SurTec 650C	6061-T6	7035	4A
	5052-H32	7157	4A

Figure 28 - Wet Tape Adhesion Test Results, 24 Hour; Primer (MIL-PRF-23377) - PPG CA7233

Pretreatment	Alloy	Panel #	Evaluation
Alodine T 5900 RTU	6061-T6	2036	5A
	5052-H32	2158	5A
Iridite NCP	6061-T6	3036	5A
	5052-H32	3158	5A
Metalast HF	6061-T6	4036	5A
	5052-H32	4158	5A
Metalast HF-EPA	6061-T6	5036	5A
	5052-H32	5158	5A
SurTec 650	6061-T6	6036	5A
	5052-H32	6158	5A
SurTec 650C	6061-T6	7036	5A
	5052-H32	7158	5A

Figure 29 - Wet Tape Adhesion Test Results, 24 Hour; Test Results; Primer (MIL-PRF-85582) - Deft 44-GN-07A

3.6.4 Test Results – Wet Tape Adhesion, 96 Hour Immersion at 120°F

Test results from wet tape adhesion testing, 96 hour immersion at 120°F, are contained in Figure 30 and Figure 31. Photographs are included in Appendix I. Only two hexavalent chrome free pretreatments, Iridite NCP and Metalast HF, with PPG CA7233 primer received a perfect 5A rating on 5052-H32 and 6061-T6 test panels. Results for SurTec 650 with PPG CA7233 primer were mixed; a perfect rating was recorded for the 6061-T6 test panel while a failing rating of 3A was recorded for the 5052-H32 test panel. Alodine T 5900 RTU, Metalast HF-EPA, and SurTec 650 with PPG CA7233 primer received a failing rating of 3A on both (5052-H32 and 6061-T6) test panels. Test panels with Deft 44-GN-07A primer were rated as flawless across all test panels regardless of pretreatment or alloy combination. See the comment in section 3.5.3 regarding coating thickness of PPG CA7233.

Pretreatment	Alloy	Panel #	Evaluation
Alodine T 5900 RTU	6061-T6	2035	3A
	5052-H32	2157	3A
Iridite NCP	6061-T6	3035	5A
	5052-H32	3157	5A
Metalast HF	6061-T6	4035	5A
	5052-H32	4157	5A
Metalast HF-EPA	6061-T6	5035	3A
	5052-H32	5157	3A
SurTec 650	6061-T6	6035	5A
	5052-H32	6157	3A
SurTec 650C	6061-T6	7035	3A
	5052-H32	7157	3A

Figure 30 - Wet Tape Adhesion Test Results, 96 Hour @ 120°F; Primer (MIL-PRF-23377) - PPG CA7233

Pretreatment	Alloy	Panel #	Evaluation
Alodine T 5900 RTU	6061-T6	2036	5A
	5052-H32	2158	5A
Iridite NCP	6061-T6	3036	5A
	5052-H32	3158	5A
Metalast HF	6061-T6	4036	5A
	5052-H32	4158	5A
Metalast HF-EPA	6061-T6	5036	5A
	5052-H32	5158	5A
SurTec 650	6061-T6	6036	5A
	5052-H32	6158	5A
SurTec 650C	6061-T6	7036	5A
	5052-H32	7158	5A

Figure 31 - Wet Tape Adhesion Test Results, 96 Hour @ 120°F; Primer (MIL-PRF-85582) - Deft 44-GN-07A

3.7 Surface Resistance Test

Stakeholders expressed interest in having this test for comparison with the contact electrical resistance procedure listed in MIL-DTL-81706B. A major difference in the ASTM D 257 procedure is the greatly reduced applied pressure on the electrodes.

3.7.1 Test Procedure

This test was conducted per ASTM D 257 (Standard Test Methods for DC Resistance or Conductance of Insulating Materials). An Electro-Tech Systems, model 803B surface, volume resistance, and resistivity probe connected to a Fluke 8846A multimeter with 4 point hook up set to 4 point resistance measurements was used to obtain measured resistance. The 803B probe is placed onto the surface of the test panel ensuring full contact is made. Pressure is then applied to the probe by hand (see Figure 32). Resistance measurements are recorded once readings on the multimeter stabilize. Surface resistance in ohms per square is equal to measured resistance times 10. Measures were taken before and after ASMT B 117 salt spray testing.

Figure 32 - Electro-Tech Systems, Model 803B Probe

3.7.2 Evaluation Procedure

The stakeholders of the Hex Chrome Free Coatings for Electronics Applications project did not set pass / fail criteria for this test. The purpose was to compare to the existing standard to determine if a quick non-destructive analysis of coating resistance could be derived.

3.7.3 Test Results - Surface Resistance Test

Surface resistance or "sheet resistance" for this test is in ohms per square. Data is contained in Figure 33 and Figure 34. The difficulty of consistent results and uncertainty of how this test is comparable to the contact electrical resistance test per MIL-DTL-81706B calls for further analysis of the data and more side-by-side testing before a conclusion can be made regarding this test's validity for use on pretreated surfaces.

Pretreatment	Alloy	Unique Panel #	ohms per square 1	ohms per square 2	ohms per square 3	ohms per square 4	ohms per square 5	Average	Standard Deviation
Alodine 1600	6061-T6	1011	4.4	4.5	4.4	4.4	4.6	4.46	0.09
		1012	4.4	4.4	4.5	4.6	4.4	4.46	0.09
		1013	4.4	4.3	4.4	4.4	4.3	4.36	0.05
		1014	4.4	4.4	4.5	4.3	4.4	4.40	0.07
		1015	4.4	4.5	4.4	4.3	4.5	4.42	0.08
	7075-T73	1060	4.4	4.5	4.4	4.4	4.4	4.42	0.04
	2024-T3	1098	4.3	4.5	4.4	4.4	4.4	4.40	0.07
	5052-H32	1137	4.4	4.3	4.4	4.4	4.5	4.40	0.1
Alodine T 5900 RTU	6061-T6	2011	4	4.1	4.2	4.3	4.1	4.14	0.11
		2012	4.1	4.3	4.2	4.2	4.3	4.22	0.08
		2013	4.2	4.1	4.3	4.2	4.2	4.20	0.07
		2014	4	4.2	4.2	4.2	4.3	4.18	0.11
		2015	4	4.2	4.1	4.2	4	4.10	0.10
	7075-T73	2060	4	4.1	4.2	4	4.2	4.10	0.10
	2024-T3	2098	4.2	4.2	4.3	4.2	4.2	4.22	0.04
	5052-H32	2137	4.3	4.1	4.2	4.1	4.2	4.18	0.08
Iridite NCP	6061-T6	3011	4.7	4.5	4.6	4.5	4.6	4.58	0.08
		3012	4.4	4.6	4.7	4.6	4.5	4.56	0.11
		3013	4.4	4.5	4.7	4.6	4.6	4.56	0.11
		3014	4.6	4.4	4.5	4.5	4.4	4.48	0.08
		3015	4.4	4.5	4.4	4.5	4.4	4.44	0.05
	7075-T73	3060	4.4	4.6	4.4	4.5	4.4	4.46	0.09
	2024-T3	3098	4.4	4.4	4.5	4.6	4.5	4.48	0.08
	5052-H32	3137	4.5	4.4	4.4	4.5	4.4	4.44	0.05
Metalast HF	6061-T6	4011	4	4.1	4.2	4.1	4	4.08	0.08
		4012	4.2	4.1	4.3	4.2	4.4	4.24	0.11
		4013	4.3	4.1	4.3	4.2	4.3	4.24	0.09
		4014	4.3	4.1	4.3	4.2	4.2	4.22	0.08
		4015	4.1	4.1	4.2	4.1	4.2	4.14	0.05
	7075-T73	4060	4.1	4.2	4	4.1	4.2	4.12	0.08
	2024-T3	4098	4.1	4.3	4.2	4	4.2	4.16	0.11
	5052-H32	4137	4.2	4.3	4	4.1	4.2	4.16	0.11

Figure 33 – Surface Resistance Data, Pre ASTM B 117 Testing

Pretreatment	Alloy	Unique Panel #	ohms per square 1	ohms per square 2	ohms per square 3	ohms per square 4	ohms per square 5	Average	Standard Deviation
Metalast HF-EPA	6061-T6	5011	4.2	4.1	4.3	4.2	4.1	4.18	0.08
		5012	4.1	4.2	4.3	4.2	4.3	4.22	0.08
		5013	4.4	4.1	4.2	4.2	4.3	4.24	0.11
		5014	4.4	4.6	4.3	4.2	4.3	4.36	0.15
		5015	4.8	4.5	4.5	4.4	4.6	4.56	0.15
	7075-T73	5060	4.2	4.2	4.1	4.3	4.2	4.20	0.07
	2024-T3	5098	5.1	5	5.2	5.1	5.2	5.12	0.08
	5052-H32	5137	4.1	4.2	4.1	4.2	4.2	4.16	0.05
SurTec 650	6061-T6	6011	4.4	4.4	4.2	4.5	4.3	4.36	0.11
		6012	4.2	4.3	4.5	4.4	4.3	4.34	0.11
		6013	4.4	4.4	4.5	4.2	4.3	4.36	0.11
		6014	4.3	4.3	4.4	4.5	4.4	4.38	0.08
		6015	4.4	4.3	4.4	4.4	4.3	4.36	0.05
	7075-T73	6060	4.4	4.4	4.5	4.3	4.4	4.40	0.07
	2024-T3	6098	4.3	4.5	4.4	4.3	4.2	4.34	0.11
	5052-H32	6137	4.3	4.5	4.3	4.4	4.4	4.38	0.08
SurTec 650C	6061-T6	7011	4.3	4.2	4.5	4.4	4.4	4.36	0.11
		7012	4.5	4.4	4.4	4.5	4.3	4.42	0.08
		7013	4.4	4.2	4.3	4.2	4.4	4.30	0.10
		7014	4.4	4.5	4.2	4.2	4.4	4.34	0.13
		7015	4.4	4.2	4.4	4.4	4.3	4.34	0.09
	7075-T73	7060	4.2	4.4	4.4	4.4	4.3	4.34	0.09
	2024-T3	7098	4.2	4.3	4.3	4.4	4.4	4.32	0.08
	5052-H32	7137	4.3	4.5	4.3	4.4	4.5	4.40	0.10

Figure 34 - Surface Resistance Data, Pre ASTM B 117 Testing

3.8 Contact Electrical Resistance

This test is used to determine coating electrical resistance.

3.8.1 Test Procedure

This test was conducted per MIL-DTL-81706B (Chemical Conversion Materials for Coating Aluminum and Aluminum Alloys). Ten (10) replicates per substrate / per coating were prepared for this test; 5 for pre ASTM B 117 salt spray exposure measurements and 5 for post ASTM B 117 salt spray exposure measurements.

Measurements were made using two copper electrodes (1" diameter and 1.5" diameter) with end surfaces polished to a mirror finish fixed in an Instron compression tester. Before taking readings on the panels, baseline electrical resistance readings of the copper electrodes were taken. These values were subtracted from the panel electrical resistance values. The copper electrical resistance values were monitored for any increase in baseline resistance, which indicated a need to re-polish the electrodes.

When testing, the larger diameter (1.5") copper electrode was positioned on the lower Instron compression plate. The test panel was positioned on top of the larger diameter copper electrode and then the smaller diameter (1") copper electrode was centered over the lower electrode while 200 lbs of force was applied using the Instron. Once 200 lbs of force was achieved, electrical resistance readings were taken using a Hewlett-Packard 4328A milliohm meter. Probes were integrated into the copper electrodes for taking the resistance readings. Ten electrical resistance readings were taken on each panel (see Figure 35). The electrical resistance readings were averaged and the baseline copper electrode electrical resistance readings subtracted from the average; this value was divided by two to give the coating electrical resistance value.

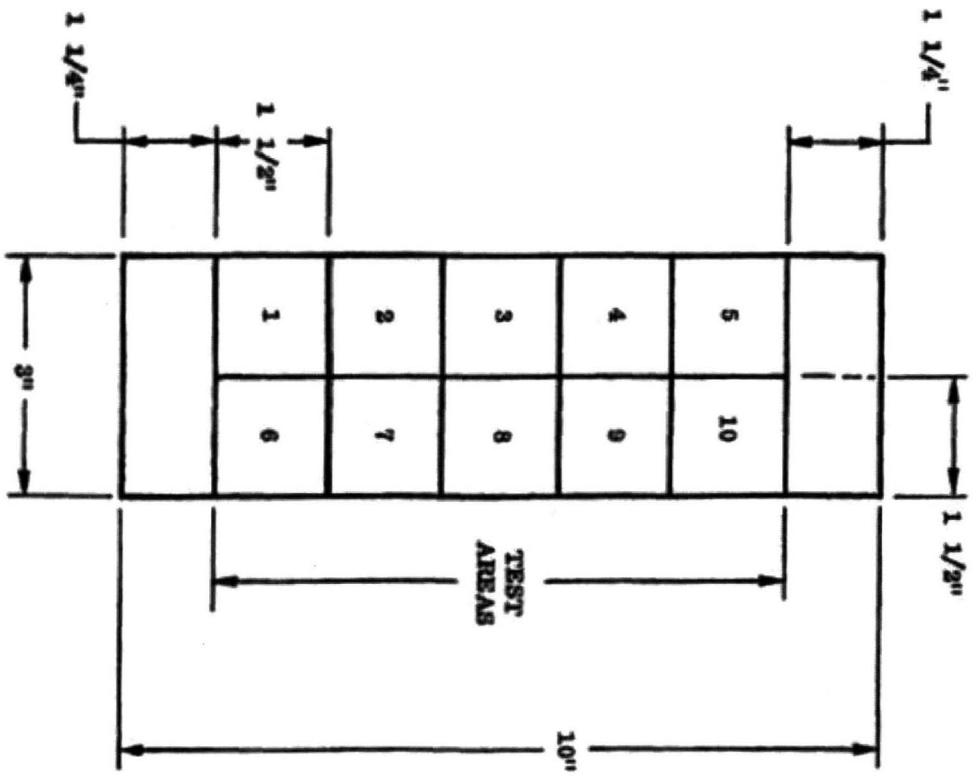

Figure 35 - Areas for measurements of electrical resistance on treated panels, MIL-DTL-81706B

3.8.2 Evaluation Procedure

Per MIL-DTL-81706B, the contact electrical resistance of aluminum alloy panels treated with class 3 materials under an applied electrode pressure of 200 pounds psi shall be not greater than 5,000 microhms psi as applied and 10,000 microhms psi after salt spray exposure. Individual readings not greater than 20 percent in excess of the specified maximums shall be acceptable, provided that the average of all readings does not exceed the specified maximum resistance.

3.8.3 Test Results - Contact Electrical Resistance

Coating electrical resistance values are provides in Figure 36. All of the pretreatments tested had coating electrical resistance values far below the specified maximum of 5,000 microhms. The electrical resistance values were not conducted after salt spray exposure due to the corrosion performance of the baseline coating.

microhms	2024-T3	5052-H32	6061-T6	7075-T73
Alodine 1600	449	422	433	349
Alodine T 5900 RTU	274	253	294	187
Iridite NCP	426	265	371	377
Metalast HF	177	41	73	278
Metalast HF-EPA	498	444	565	469
SurTec 650	600	759	647	451
SurTec 650C	572	745	702	650

Figure 36 – Contact Electrical Resistance Readings, Pre ASTM B 117

3.9 Screening Level Testing

Additional pretreatments were tested on a very limited basis in an effort to seek out new and emerging technologies. Candidates that perform well may be brought in for full testing in future projects. Since these coatings were only evaluated on a very limited basis, they are not being included in the overall Joint Test Report. Following is a list of pretreatments subjected to screening level testing:

- Alodine EC2
- Corrlink 30A
- Missouri S&T (aged samples)
- PPG X-Bond 4000
- Missouri S&T (newer samples)
- EonCoat
- Metalast TCPCC-600P
- NANOMYTE PT-10
- NANOMYTE TC-4001
- Alodine 160/161
- Alodine 5923 plus
- Interlox 5705
- MAPSIL SILICo

Pretreatments for this screening level test were provided by the vendor, and provide an indication of how some lower TRL or new coatings might perform. Vendor provided coatings that perform well should be considered for future phases of testing but panels should be prepared by a third party.

Several materials performed well through 168 hours of testing, including Alodine EC2, Corrlink 30A and both aged and new versions of Missouri S&T pretreatments. It should be noted that Alodine EC2 passed corrosion testing through 1000 hours when the test was ended. Alodine EC2 is an electro-ceramic coating that may have flexibility issues for extreme environments like those seen in space, which should be considered. It is also a coating that is relatively thick, though not a pretreatment or primer in the traditional sense, its highest potential applications should be determined prior to future testing. While not as robust as Alodine EC2 in limited testing, Corrlink 30A and Missouri S&T coatings also performed well and passed the 168 hour requirement. Corrlink is a patented "smart coating" and Missouri S&T is a rare-earth element based coating, both of which should be monitored moving forward and considered for future testing.

Pretreatment	Alloy	168 Hour Testing	Testing to Failure
Alodine EC2	2024-T3	Pass	Pass @ 1008 hr.
Corrlink 30A	2024-T3	Pass	Fail @ 336 hr.
Missouri S&T (aged)	2024-T3	Pass	Fail @ 336 hr.
PPG X-Bond 4000	2024-T3	Fail	Fail @ 168 hr.
Missouri S&T (new)	2024-T3	Pass	Fail @ 336 hr.
EonCoat	2024-T3	Fail	Fail @ 168 hr.
Metalast TCPCC-600P	2024-T3	Fail	Fail @ 168 hr.
NANOMYTE PT-10	2024-T3	Not Tested	Fail @ 168 hr.
NANOMYTE TC-4001	2024-T3	Not Tested	Fail @ 168 hr.

Figure 37 - Screening Level Testing Salt Fog Testing Results

4 Results Summary

The results from laboratory corrosion testing are contained in Figure 38. Alodine 1600, the control pretreatment, did not perform as expected. Following ASTM B 117 salt spray exposure, 168 hours, all of the test panels with Alodine 1600 were deemed failed. This unexpected result brings into question the compatibility of Alodine 1600 and the panel preparation procedure selected for this project. Following ASTM G 85, Annex 5 cyclic corrosion testing, test panels with Alodine 1600 revealed a clear trend with respect to pretreatment performance by alloy. Alodine 1600 on alloys known for their resistance to corrosion showed no evidence of corrosion when compared to unexposed control panels. Alodine 1600 on 2024-T3 and 7075-T73 alloys were determined failed after 168 hours of cyclic corrosion testing. These alloys are known to be more susceptible to corrosion due to their higher copper content but typically Alodine 1600 and other hexavalent chrome containing pretreatments are able to protect them adequately. Results from cyclic corrosion testing again bring into question the compatibility of Alodine 1600 and the panel preparation procedure selected for this project.

Following ASTM B 117 salt spray testing, 168 hours, hexavalent chrome free pretreatments revealed a clear trend with respect to pretreatment performance by alloy. Pretreatments on alloys known for their resistance to corrosion showed no evidence of corrosion when compared to unexposed control panels. Pretreatments on 2024-T3 and 7075-T73 alloys were determined failed after salt spray exposure. Such a strong delineation of the data across alloy type, regardless of hexavalent chrome free pretreatment, was not expected. This unexpected result brings into question the panel preparation procedure selected for this project. Following ASTM G85, Annex 5 cyclic corrosion testing, the hexavalent chrome free pretreatments revealed a clear trend with respect to pretreatment performance by alloy. As with ASTM B 117 test results, pretreatments on alloys known for their resistance to corrosion showed no evidence of corrosion when compared to unexposed control panels following cyclic corrosion testing. There was one exception to the trend; Metalast HF did show signs of corrosion on 6061-T6 and 5052-H32 alloys.

For ASTM B 117 salt spray testing, to failure, please review Section 3.1.4 for details on how the test panels were handled prior to testing.

The results from tape adhesion testing are contained in Figure 39 and Figure 40. Overall, pretreatments with Deft 44-GN-07A had higher and more consistent ratings than pretreatments with PPG CA7233 primer. There are few exceptions, Iridite NCP with PPG CA7233 primer preformed really well minus one off reading. Metalast HF with PPG CA7233 primer was rated perfect across all three adhesion tests. The discrepancy in results may be attributed to the fact that the PPG CA7233 coating was thicker than specified in the specifications for this test after it was applied. It is recommended that this test be re-run if funding permits for the most promising pretreatments in the next phase of testing.

Pretreatment	Alloy	B117 @ 168 Hours	G85 @ 168 Hours	B117 to Fail*
Alodine 1600	6061-T6	Fail	Pass	4 of 5 Pass @ 168
	7075-T73	Fail	Fail	Failed @ 168
	2024-T3	Fail	Fail	Failed @ 168
	5052-H32	Fail	Pass	1 of 5 Pass @ 168
Alodine 5900	6061-T6	Pass	Pass	3 of 5 Pass @ 168
	7075-T73	Fail	Fail	Failed @ 168
	2024-T3	Fail	Fail	Failed @ 168
	5052-H32	Pass	Pass	Pass @ 1008
Iridite NCP	6061-T6	Pass	Pass	4 of 5 Pass @ 168
	7075-T73	Fail	Fail	Failed @ 168
	2024-T3	Fail	Fail	Failed @ 168
	5052-H32	Pass	Pass	4 of 5 Pass @ 1008
Metalast HF	6061-T6	Pass	Fail	1 of 5 Pass @ 168
	7075-T73	Fail	Fail	Failed @ 168
	2024-T3	Fail	Fail	Failed @ 168
	5052-H32	Pass	Fail	2 of 5 Pass @ 1008
Metalast HF-EPA	6061-T6	Pass	Pass	4 of 5 Pass @ 168
	7075-T73	Fail	Fail	Failed @ 168
	2024-T3	Fail	Fail	Failed @ 168
	5052-H32	Pass	Pass	Pass @ 1008
Surtec 650	6061-T6	Pass	Pass	4 of 5 Pass @ 168
	7075-T73	Fail	Fail	Failed @ 168
	2024-T3	Fail	Fail	Failed @ 168
	5052-H32	Pass	Pass	Pass @ 1008
Surtec 650C	6061-T6	Pass	Pass	4 of 5 Pass @ 168
	7075-T73	Fail	Fail	Failed @ 168
	2024-T3	Fail	Fail	Failed @ 168
	5052-H32	Pass	Pass	4 of 5 Pass @ 1008

*Note - All five 6061-T6 test panels as well as 1 of 5 test panels for 7075-T73, 2024-T3, and 5052-H32 for all pretreatments were used for ASTM D 257 readings. Test panels were not tested at the same time as the others listed in the table. Testing with these test panels was stopped after 168 hours.

Figure 38 – Combined Corrosion Test Results

Pretreatment	Alloy	Wet Tape Adhesion		Cross-Cut Tape
		24 hr. Immersion	4 Day Immersion @ 120°F	Rating
Alodine T 5900 RTU	6061-T6	3A	3A	1B
				1B
	5052-H32	5A	3A	1B
				1B
Iridite NCP	6061-T6	5A	5A	5B
				2B
	5052-H32	5A	5A	4B
				5B
Metalast HF	6061-T6	5A	5A	5B
				5B
	5052-H32	5A	5A	5B
				5B
Metalast HF-EPA	6061-T6	3A	3A	1B
				1B
	5052-H32	3A	3A	1B
				1B
SurTec 650	6061-T6	5A	5A	2B
				1B
	5052-H32	4A	3A	1B
				1B
SurTec 650C	6061-T6	4A	3A	2B
				2B
	5052-H32	4A	3A	2B
				2B

Figure 39 – Combined Adhesion Test Results; Pretreatments with PPG CA7233 primer

Pretreatment	Alloy	Wet Tape Adhesion		Cross-Cut Tape
		24 hr. Immersion	4 Day Immersion @ 120°F	Rating
Alodine T 5900 RTU	6061-T6	5A	5A	5B
				5B
	5052-H32	5A	5A	5B
				5B
Iridite NCP	6061-T6	5A	5A	5B
				5B
	5052-H32	5A	5A	5B
				5B
Metalast HF	6061-T6	5A	5A	5B
				5B
	5052-H32	5A	5A	5B
				5B
Metalast HF-EPA	6061-T6	5A	5A	5B
				5B
	5052-H32	5A	5A	5B
				5B
SurTec 650	6061-T6	5A	5A	5B
				5B
	5052-H32	5A	5A	4B
				5B
SurTec 650C	6061-T6	5A	5A	5B
				5B
	5052-H32	5A	5A	5B
				5B

Figure 40 - Combined Adhesion Test Results; Pretreatments with Deft 44-GN-07A primer

5 Recommendations

Inconsistent results across the hexavalent chrome control and hexavalent chrome free pretreatments have brought into question the panel preparation process used for this project. New panel process procedures were suggested and additional testing conducted in an effort to achieve more consistent results and provide a better basis for comparison in future phases. Further testing of some of the most promising pretreatments was also conducted.

5.1 Proposed Panel Preparation Procedures

The following two processes were developed with vendor and stakeholder input for further testing and analysis.

5.1.1 Process 1

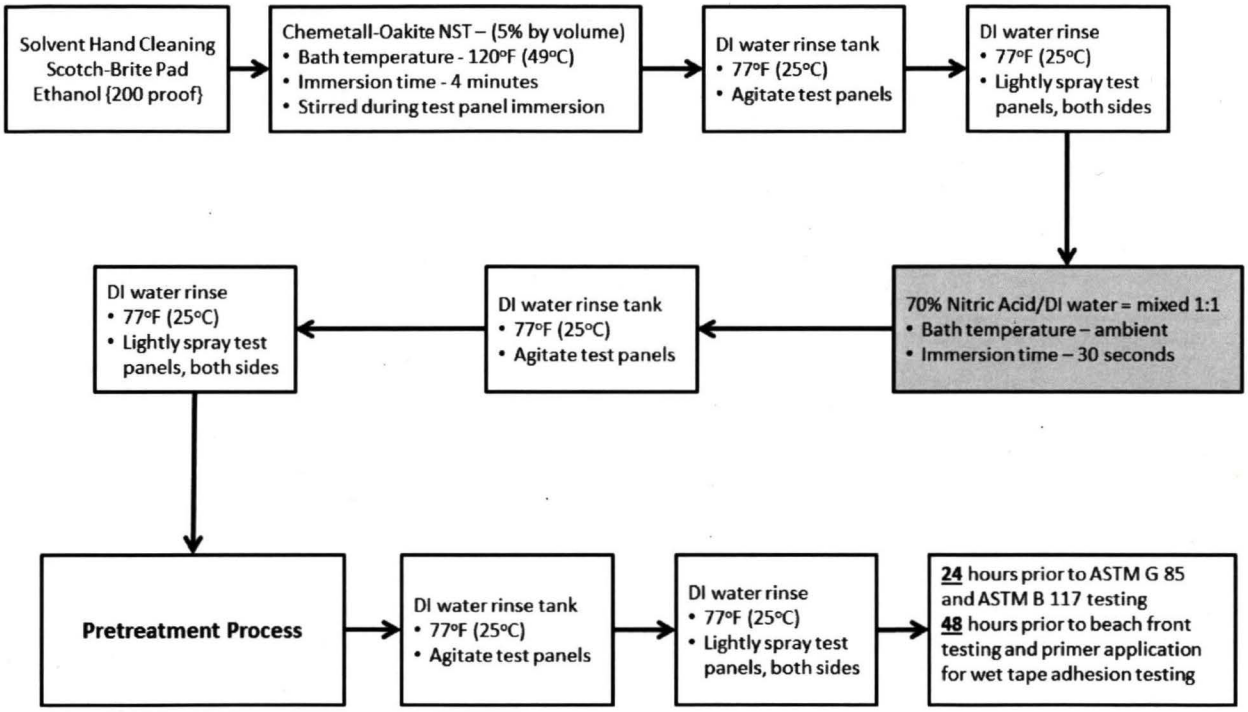

Figure 41 - Flow Diagram, Initial Baseline Coating Process 1

5.1.2 Process 2

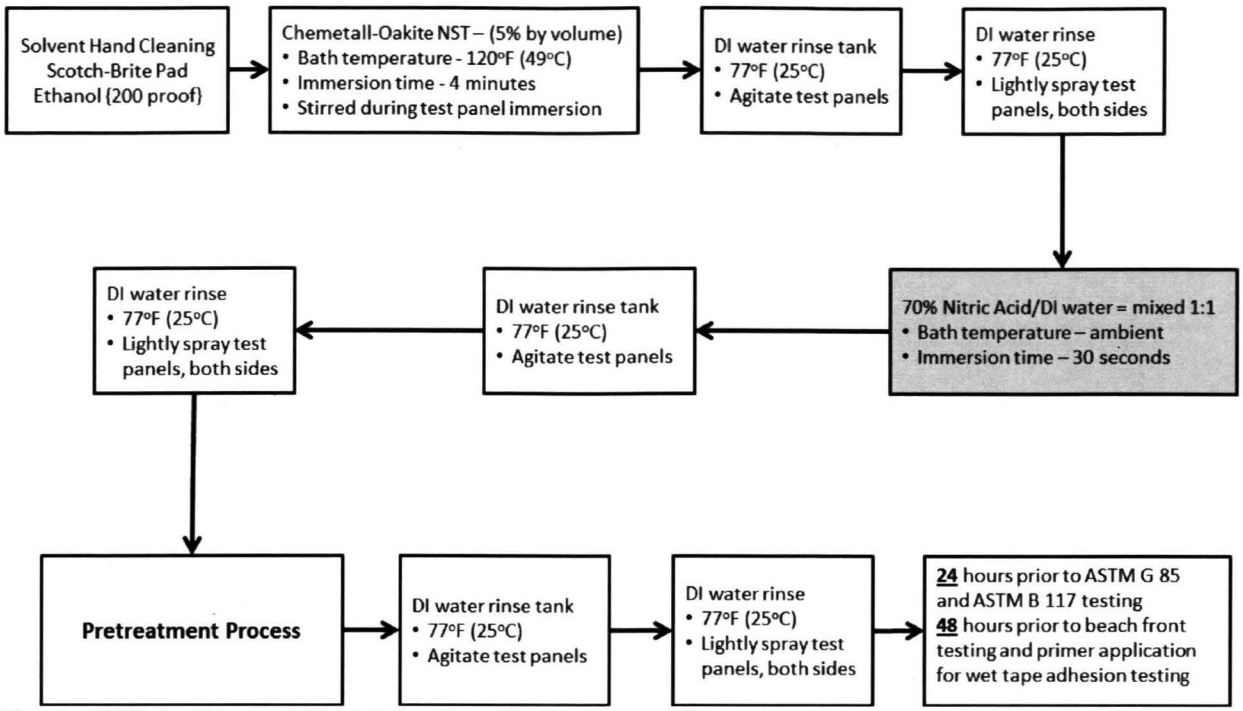

Figure 42 - Flow Diagram, Initial Baseline Coating Process 2

5.2 Re-testing Salt Spray Resistance

5.2.1 Test Procedure

There were five (5) replicates per substrate / per coating system. Test panels were subjected to a 5 percent NaCl salt spray, pH-adjusted to a range of 6.5 – 7.2, in accordance with ASTM B 117 (Standard Practice for Operating a Salt Spray (Fog) Apparatus).

5.2.2 Evaluation Procedure

The evaluation procedure entailed inspecting each panel at intervals of 168 hours and performing a pit count using the naked eye. No more than 5 isolated spots or pits and none larger than 0.031 inch in diameter were allowed per test specimen. No more than 15 isolated spots or pits and none larger than 0.031 inch in diameter, were allowed on the combined surface area of all five test specimens. Areas within 0.25 inch (6.35 millimeters [mm]) from the edges of the panel, the identification markings, panel holding points during processing or salt spray exposure, and defects were not evaluated. Changes in color and appearance were noted but not used to reject specimen.

5.2.3 Test Results – ASTM B 117, 840 hours

Figure 43 through Figure 46 show the results of when panels were deemed failed or otherwise pulled from test chambers. Process 2 performed well on the selected baseline, Alodine 1200S. The project team consulted with coating manufacturers to determine why similar results were not experienced with the trivalent and non-chrome coating alternatives.

Alodine 1200S is a true conversion coating. This means that when the oxide layer on the aluminum is removed in the deoxidizer step the conversion coating makes a new chrome oxide layer across the aluminum. (Aluminum does not exist in nature as aluminum; it exists as aluminum oxide or aluminum

silicate.) Trivalent chrome seals the oxide layer, putting a zirconium/trivalent chrome coating across the oxide. This is why trivalent chrome does not work with aluminum etches and deoxidizers that contain fluoride (with an etch rate above 0.1 mils/side/hour). Most commercial aerospace specifications require a deoxidizer that etches at a rate of 0.1 to 0.4 mils/side/hour. This is one of the reasons why industry is having a hard time moving to trivalent chrome. This is also why trivalent chrome works very well as a seal for anodize. Nitric acid is a known great deoxidizer. It provides next to no etch rate. The nitric acid bath will age very quickly and begin to redeposit smut onto parts. This can cause issues with the trivalent chrome conversion coating. To counter this aging and not use hexavalent chrome industry uses an iron based deoxidizer that also contains fluoride. Iron based deoxidizers are prone to periodic and random iron adhesion to the aluminum causing sporadic failures.

Pretreatment	Process	Alloy	168 Hours	336 Hours	504 Hours	672 Hours	840 Hours
Alodine 1200S	1	2024-T3	Fail				
			Pass & RTT	Fail			
			Pass & RTT	Fail			
			Fail				
			Fail				
Alodine 1200S	1	2024-T3*	Fail				
Alodine 1200S	1	2219	Fail				
			Fail				
			Fail				
			Fail				
			Fail				
Alodine 1200S	1	6061-T6	Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
Alodine 1200S	1	6061-T6*	Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Fail
Alodine 1200S	1	7075-T6	Pass & RTT	Pass & RTT	Fail	Fail	
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Fail	Fail	
			Pass & RTT	Pass & RTT	Fail	Fail	
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Fail
Alodine 1200S	1	7075-T6*	Pass & RTT	Pass & RTT	Fail	Fail	
RTT = Returned To Testing							
* Test panels purchased through AnaCon Laboratories; 3x10x.040", PVC cover both sides							
Testing stopped after 840 hours							

Pretreatment	Process	Alloy	168 Hours	336 Hours	504 Hours	672 Hours	840 Hours
Alodine 1200S	2	2024-T3	Fail				
			Fail				
			Fail				
			Fail				
			Fail				
Alodine 1200S	2	2219	Fail				
			Fail				
			Fail				
			Fail				
			Fail				
Alodine 1200S	2	6061-T6	Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
Alodine 1200S	2	7075-T6	Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Fail
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Fail
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Fail
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Fail
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Fail

Figure 43 – ASTM B 117 Results, To Failure; Alodine 1200S

Pretreatment	Process	Alloy	168 Hours	336 Hours	504 Hours	672 Hours	840 Hours
Metalast TCP-HF	1	2024-T3	Pass & RTT	Fail			
			Pass & RTT	Fail			
			Pass & RTT	Fail			
			Pass & RTT	Fail			
			Pass & RTT	Fail			
Metalast TCP-HF	1	2024-T3*	Pass & RTT	Pass & RTT	Fail	Fail	
Metalast TCP-HF	1	2219	Fail				
			Fail				
			Fail				
			Fail				
			Fail				
Metalast TCP-HF	1	6061-T6	Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
Metalast TCP-HF	1	6061-T6*	Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
Metalast TCP-HF	1	7075-T6	Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Fail
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Fail
Metalast	1	7075-T6*	Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass

RTT = Returned To Testing

* Test panels purchased through AnaCon Laboratories; 3x10x.040", PVC cover both sides

Testing stopped after 840 hours

Pretreatment	Process	Alloy	168 Hours	336 Hours	504 Hours	672 Hours	840 Hours
Metalast TCP-HF	2	2024-T3	Pass & RTT	Fail			
			Pass & RTT	Pass & RTT	Fail		
			Pass & RTT	Fail			
			Pass & RTT	Fail			
			Pass & RTT	Fail			
Metalast TCP-HF	2	2219	Fail				
			Fail				
			Fail				
			Fail				
			Fail				
Metalast TCP-HF	2	6061-T6	Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
Metalast TCP-HF	2	7075-T6	Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass

Figure 44 – ASTM B 117 Results, To Failure; Metalast HF

Pretreatment	Process	Alloy	168 Hours	336 Hours	504 Hours	672 Hours	840 Hours
SurTec 650C	1	2024-T3	Fail				
			Fail				
			Fail				
			Fail				
			Fail				
SurTec 650C	1	2024-T3*	Pass & RTT	Fail			
SurTec 650C	1	2219	Fail				
			Fail				
			Fail				
			Fail				
			Fail				
SurTec 650C	1	6061-T6	Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
SurTec 650C		6061-T6*	Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
SurTec 650C	1	7075-T6	Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
SurTec 650C		7075-T6*	Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass

RTT = Returned To Testing

* Test panels purchased through AnaCon Laboratories; 3x10x.040", PVC cover both sides

Testing stopped after 840 hours

Pretreatment	Process	Alloy	168 Hours	336 Hours	504 Hours	672 Hours	840 Hours
SurTec 650C	2	2024-T3	Fail				
			Fail				
			Fail				
			Fail				
			Fail				
SurTec 650C	2	2219	Fail				
			Fail				
			Fail				
			Fail				
			Fail				
SurTec 650C	2	6061-T6	Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
SurTec 650C	2	7075-T6	Pass & RTT	Pass & RTT	Pass & RTT	Fail	
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Fail	

Figure 45 – ASTM B 117 Results, To Failure; SurTec 650C Results

Pretreatment	Process	Alloy	168 Hours	336 Hours	504 Hours	672 Hours	840 Hours
Iridite NCP	1	2024-T3	Fail				
			Fail				
			Fail				
			Fail				
			Fail				
Iridite NCP	1	2024-T3*	Fail				
Iridite NCP	1	2219	Fail				
			Fail				
			Fail				
			Fail				
			Fail				
Iridite NCP	1	6061-T6	Pass & RTT	Pass & RTT	Fail		
			Fail				
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
Iridite NCP	1	6061-T6*	Fail				
Iridite NCP	1	7075-T6	Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Fail			
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Pass
			Pass & RTT	Fail			
			Pass & RTT	Pass & RTT	Pass & RTT	Fail	
Iridite	1	7075-T6*	Pass & RTT	Fail			

RTT = Returned To Testing

* Test panels purchased through AnaCon Laboratories; 3x10x.040", PVC cover both sides

Testing stopped after 840 hours

Pretreatment	Process	Alloy	168 Hours	336 Hours	504 Hours	672 Hours	840 Hours
Iridite NCP	2	2024-T3	Fail				
			Fail				
			Fail				
			Fail				
			Fail				
Iridite NCP	2	2219	Fail				
			Fail				
			Fail				
			Fail				
			Fail				
Iridite NCP	2	6061-16	Pass & RTT	Pass & RTT	Pass & RTT	Fail	
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Fail
			Pass & RTT	Fail			
			Pass & RTT	Fail			
			Pass & RTT	Pass & RTT	Pass & RTT	Pass & RTT	Fail
Iridite NCP	2	7075-T6	Fail				
			Fail				
			Fail				
			Fail				
			Fail				

Figure 46 – ASTM B 117 Results, To Failure; Iridite NCP Results

5.3 Coating Process Optimization

The project team ran experiments in the lab to investigate the effect of immersion time on process results by using combinations of deoxidizer and pretreatment bath immersion times within Process 1 and Process 2. Figure 47 through Figure 50 show the flow diagrams for the permutations analyzed.

5.3.1 Baseline Coating on 2024-T3 and 7075-T6

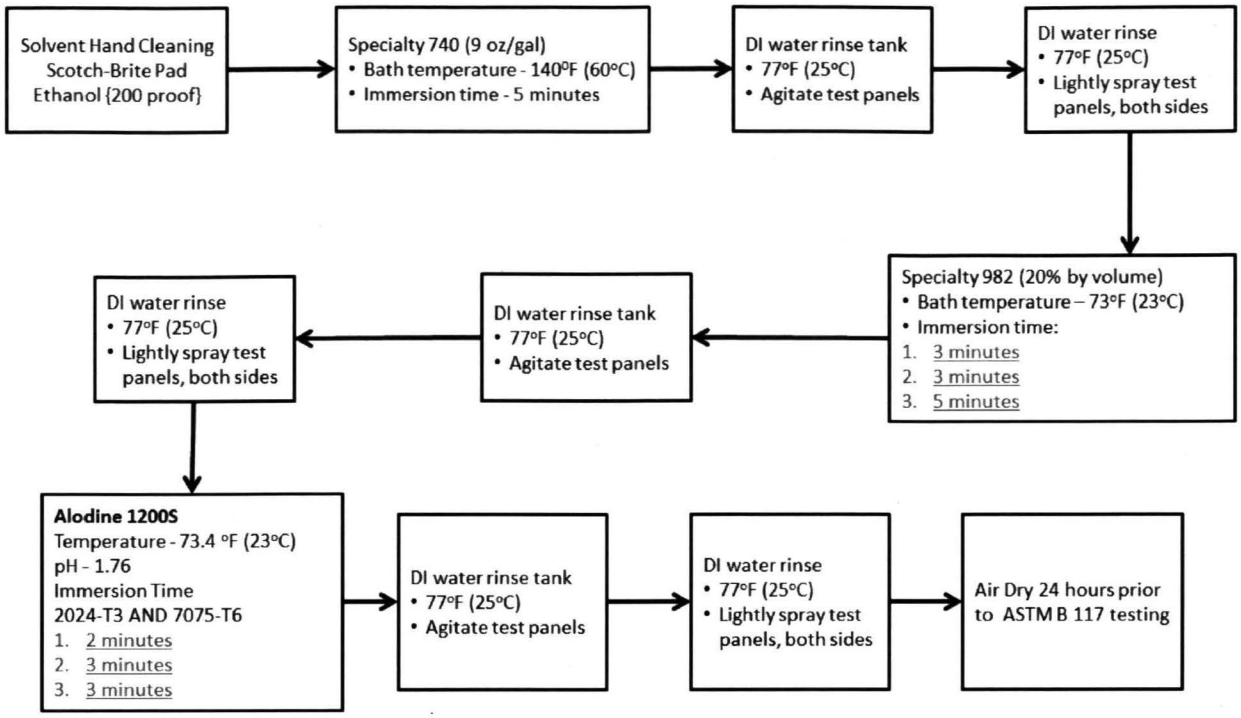

Figure 47 – Flow Diagram, Baseline Coating Process 2 on 2024-T3 and 7075-T6

5.3.2 Baseline Coating on 2219

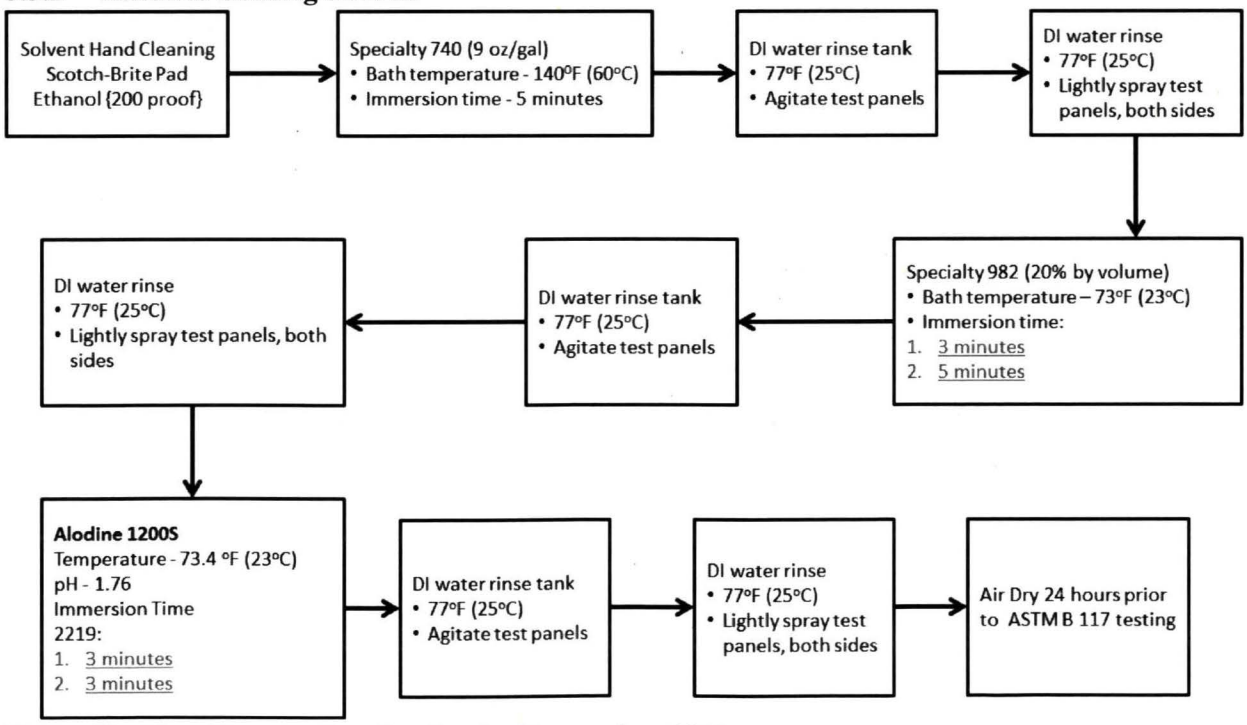

Figure 48 – Flow Diagram, Baseline Coating Process 2 on 2219

5.3.3 Trivalent Coatings on 2024-T3

5.3.3.1 Nitric Deoxidizer

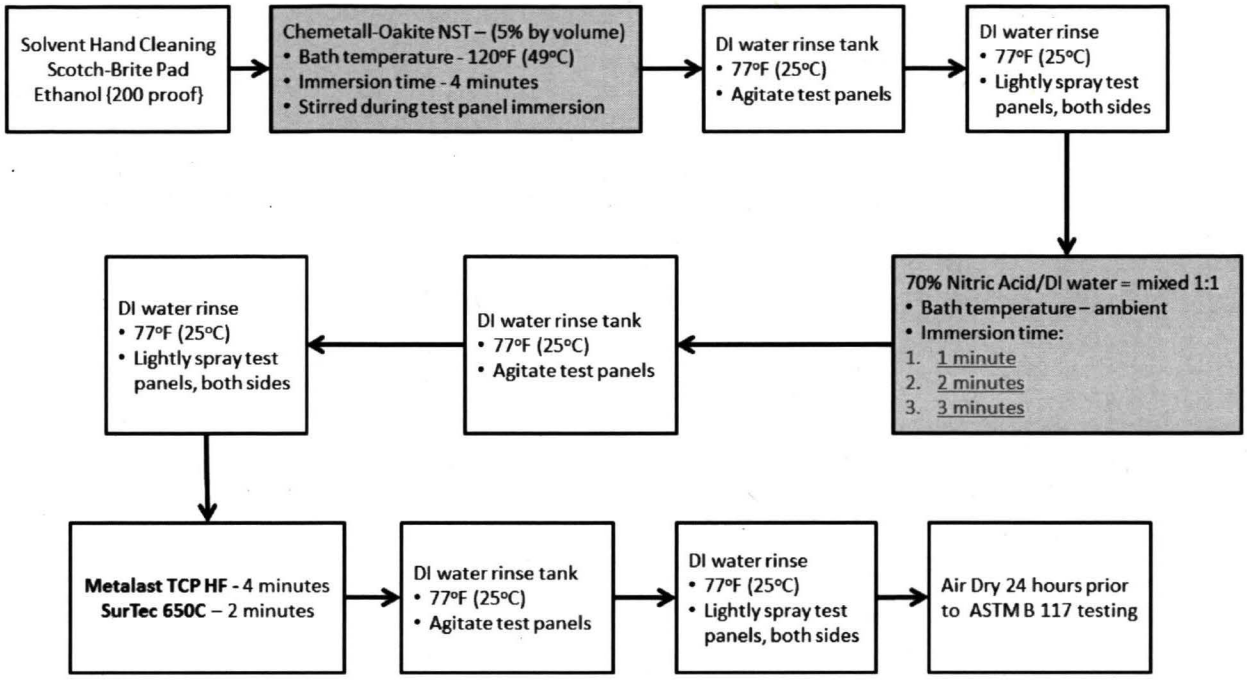

Figure 49 – Flow Diagram, Trivalent Coating Process 1 on 2024-T3

5.3.3.2 Specialty 982

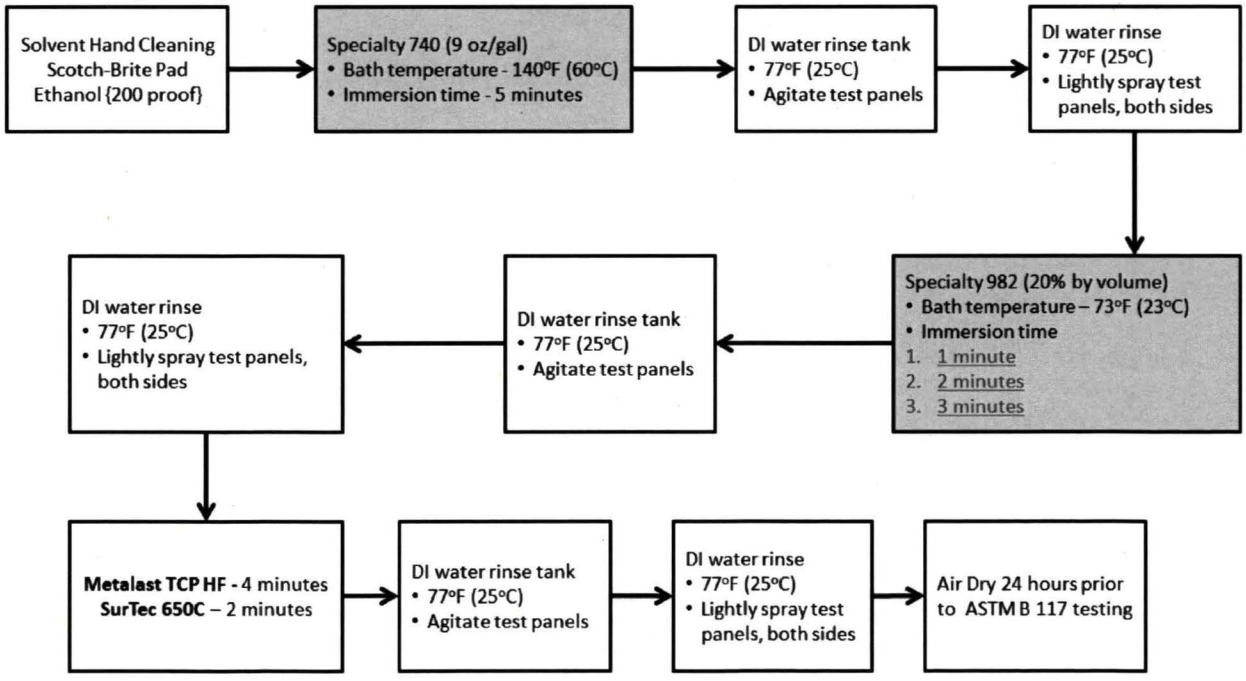

Figure 50 – Flow Diagram, Trivalent Coating Process 2 on 2024-T3

5.3.4 Test Results – ASTM B 117, to failure

Figure 51 through Figure 57 show the results of when panels were deemed failed or otherwise pulled from test chambers. Photographs are included in Appendix J.

Specialty 982 Deoxidizer			
3 min de-ox / 2 min Alodine 1200S	ASTM B117		
	Pit Count 168 Hours	Pit Count 336 Hours	Pit Count 504 Hours
A20 100	5+	N/A	N/A
A20 101	0	5+	N/A
A20 102	5+	N/A	N/A
3 min de-ox / 3 min Alodine 1200S	ASTM B117		
	Pit Count 168 Hours	Pit Count 336 Hours	Pit Count 504 Hours
A20 012	1	5+	N/A
A20 013	0	5+	N/A
A20 014	0	5+	N/A
5 min de-ox / 3 min Alodine 1200S	ASTM B117		
	Pit Count 168 Hours	Pit Count 336 Hours	Pit Count 504 Hours
A20 002	0	1	5+
A20 003	0	1	5+
A20 004	0	1	5+

Figure 51 – Alodine 1200S on 2024-T3, Process 2

Specialty 982 Deoxidizer					
3 min de-ox / 2 min Alodine 1200S	ASTM B117				
	Pit Count 168 Hours	Pit Count 336 Hours	Pit Count 504 Hours	Pit Count 672 Hours	Pit Count 840 Hours
A7 004	0	0	0	2	0
A7 005	0	0	0	0	0
A7 006	0	0	0	0	0
Pits observed are attributed to test panel damage, scratches and dings					
Testing stopped after 840 hours					
3 min de-ox / 3 min Alodine 1200S	ASTM B117				
	Pit Count 168 Hours	Pit Count 336 Hours	Pit Count 504 Hours	Pit Count 672 Hours	Pit Count 840 Hours
A7 001	0	0	0	0	0
A7 002	0	0	0	2	1
A7 003	0	0	0	0	0
Pits observed are attributed to test panel damage, scratches and dings					
Testing stopped after 840 hours					
5 min de-ox / 3 min Alodine 1200S	ASTM B117				
	Pit Count 168 Hours	Pit Count 336 Hours	Pit Count 504 Hours	Pit Count 672 Hours	Pit Count 840 Hours
A7 013	0	0	0	2	0
A7 014	0	0	0	0	0
A7 015	0	0	0	2	0
Testing stopped after 840 hours					

Figure 52 – Alodine 1200S on 7075-T6, Process 2

Specialty 982 Deoxidizer			
3 min de-ox / 3 min Alodine 1200S	ASTM B117		
	Pit Count 168 Hours	Pit Count 336 Hours	Pit Count 504 Hours
22 01	5+	N/A	N/A
22 02	5+	N/A	N/A
22 03	5+	N/A	N/A
5 min de-ox / 3 min Alodine 1200S	ASTM B117		
	Pit Count 168 Hours	Pit Count 336 Hours	Pit Count 504 Hours
22 04	5+	N/A	N/A
22 05	5+	N/A	N/A
22 06	5+	N/A	N/A

Figure 53 – Alodine 1200S on 2219, Process 2

Metalast TCP-HF	ASTM B117
1 minute in deoxidizer	168 Hours
M20 001	5+
M20 002	5+
M20 003	5+
2 minutes in deoxidizer	168 Hours
M20 004	5+
M20 005	5+
M20 006	5+
3 minutes in deoxidizer	168 Hours
M20 007	5+
M20 008	5+
M20 009	5+

Figure 54 – Metalast HF on 2024-T3, Process 1

SurTec 650C	ASTM B117
1 minute in deoxidizer	168 Hours
S20 001	5+
S20 002	5+
S20 003	5+
2 minutes in deoxidizer	168 Hours
S20 004	5+
S20 005	5+
S20 006	5+
3 minutes in deoxidizer	168 Hours
S20 007	5+
S20 008	5+
S20 009	5+

Figure 55 – SurTec 650C on 2024-T3, Process 1

Metalast TCP-HF	ASTM B117	
1 minute in deoxidizer	168 Hours	336 Hours
M20 010	1	5+
M20 011	0	5+
M20 012	5+	N/A
2 minutes in deoxidizer	168 Hours	336 Hours
M20 013	0	5+
M20 014	5+	N/A
M20 015	5+	N/A
3 minutes in deoxidizer	168 Hours	336 Hours
M20 016	3	5+
M20 017	0	5+
M20 018	1	5+

Figure 56 – Metalast HF on 2024-T3, Process 2

SurTec 650C	ASTM B117
1 minute in deoxidizer	168 Hours
S20 010	5+
S20 011	5+
S20 012	5+
2 minutes in deoxidizer	168 Hours
S20 013	5+
S20 014	5+
S20 015	5+
3 minutes in deoxidizer	168 Hours
S20 016	5+
S20 017	5+
S20 018	5+

Figure 57 – SurTec 650C on 2024-T3, Process 2

5.4 Proposed Testing

The following testing procedures have been tentatively selected to retest the performance of hexavalent chrome free pretreatments in conjunction with the newly proposed panel preparation process. A more detailed report outlining specific recommendations will be delivered separately from this report.

- ASTM D 257
- MIL-DTL-81706B, Contact electrical resistance
- ASTM B 117 – to failure
- ASTM G85 {A5} – to failure
- Beach front
- Patti Jr. Pull-Off Adhesion
- Wet Tape Adhesion: 24 and 4 day (heated)
- Coating Weight

Appendix A –
Panel Photographs - ASTM B-117; 168 Hours

Alodine 1600

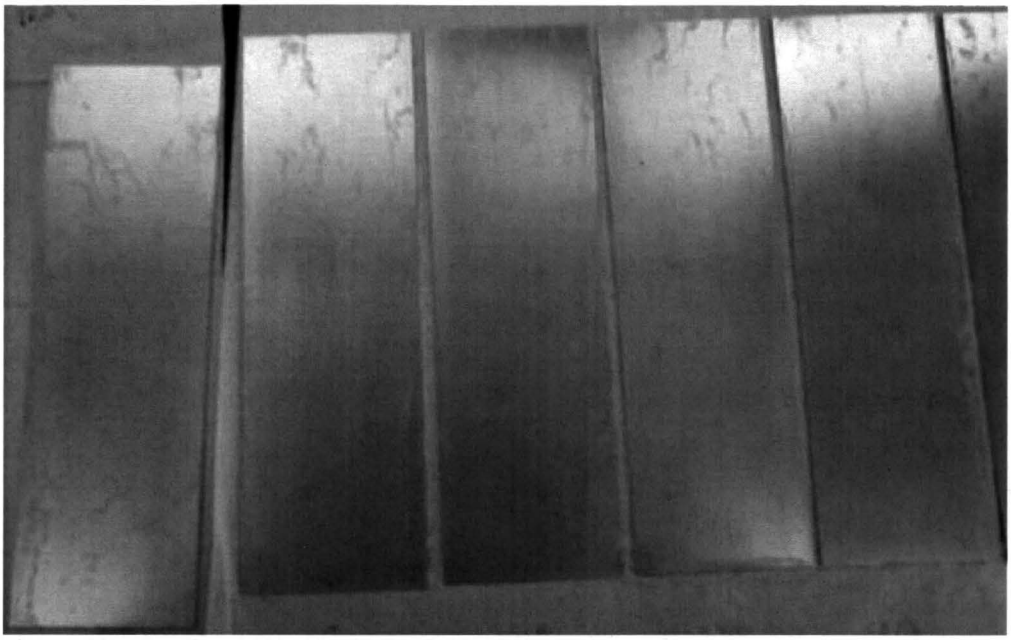

Figure 58 – Alodine 1600, 1006 – 1010 (FAIL)

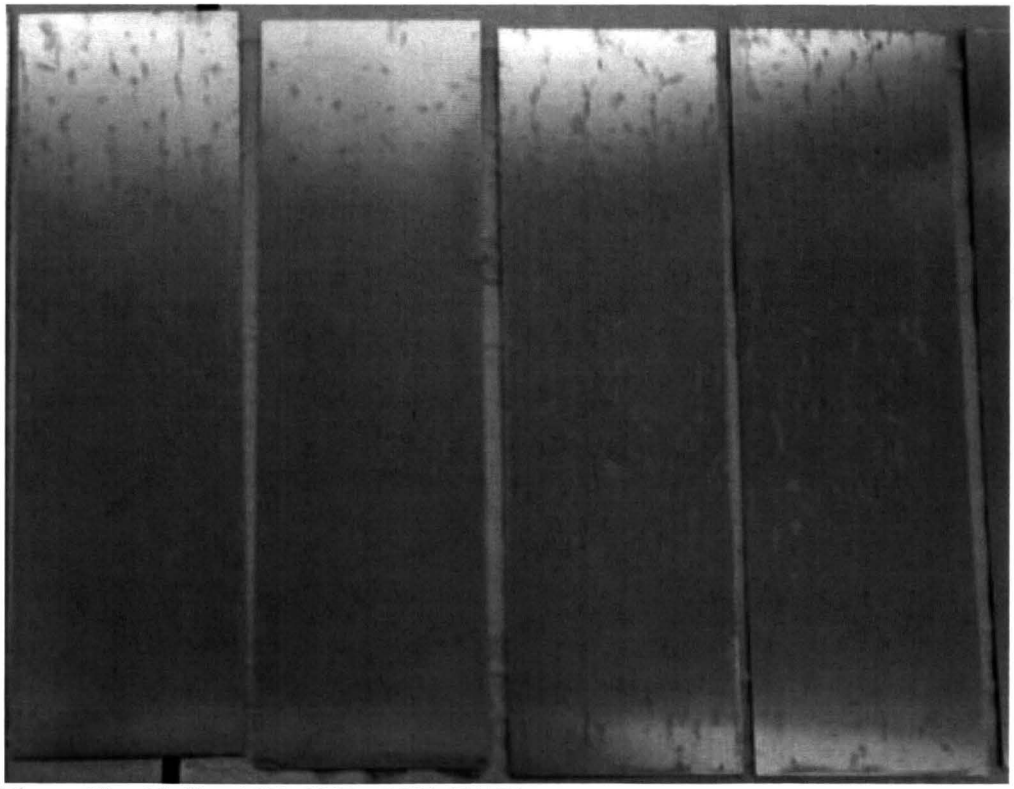

Figure 59 – Alodine 1600, 1051 – 1054 (FAIL)

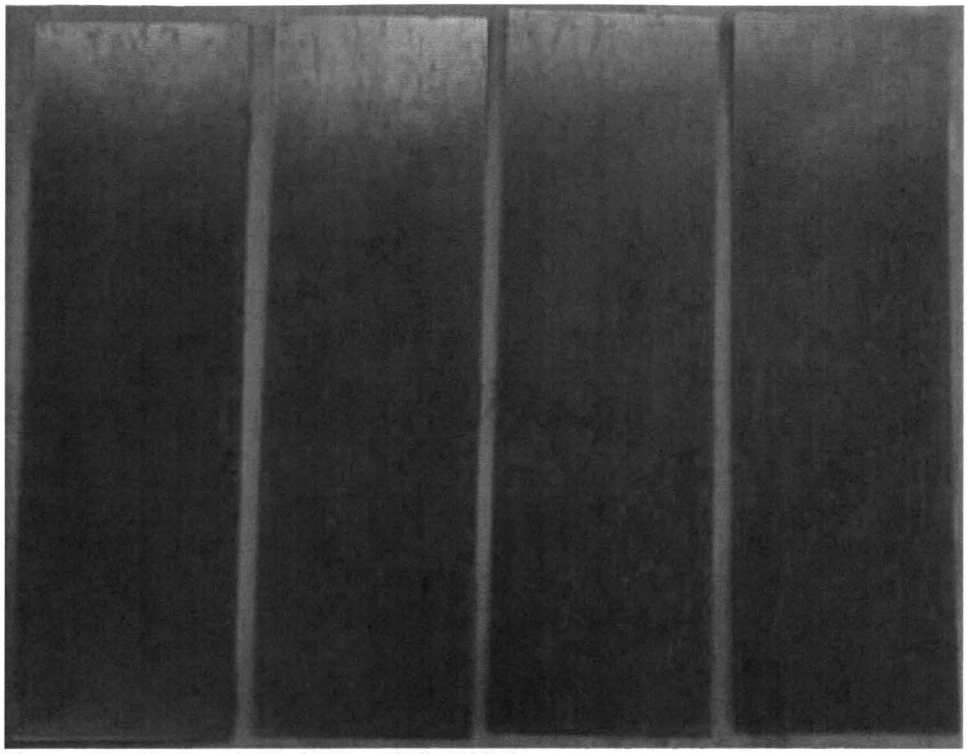

Figure 60 - Alodine 1600, 1090 – 1093 (FAIL)

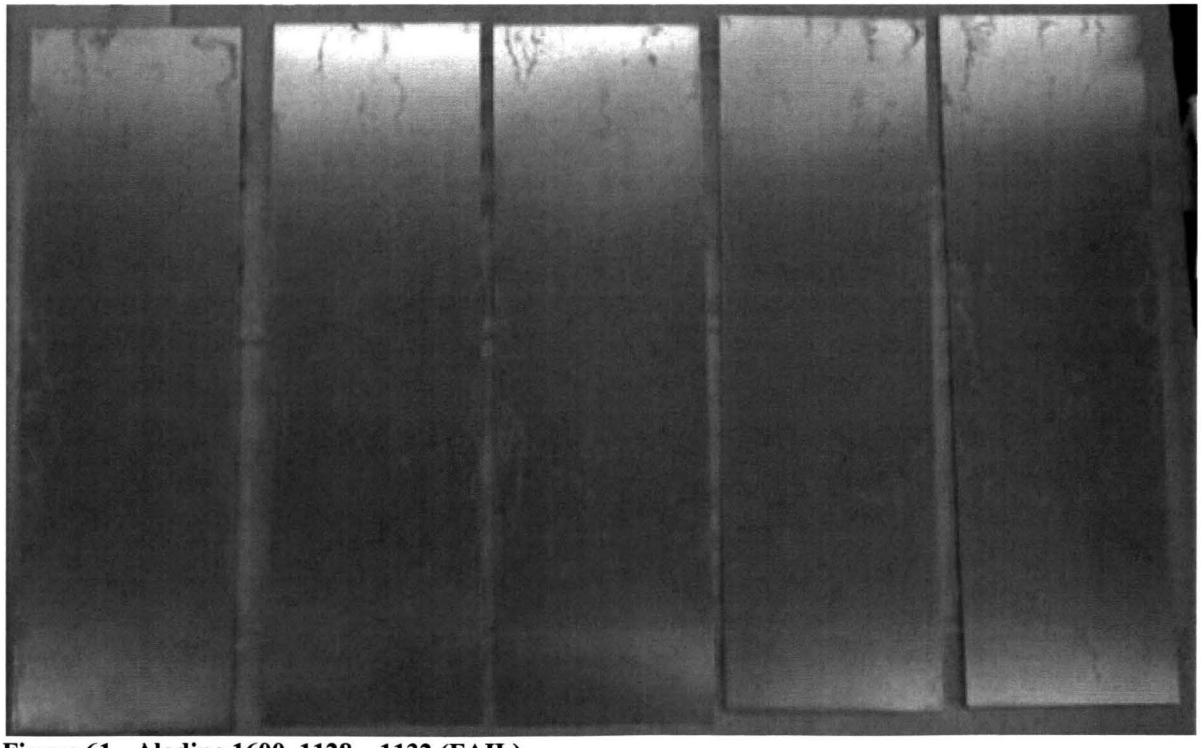

Figure 61 - Alodine 1600, 1128 – 1132 (FAIL)

Alodine T 5900 RTU

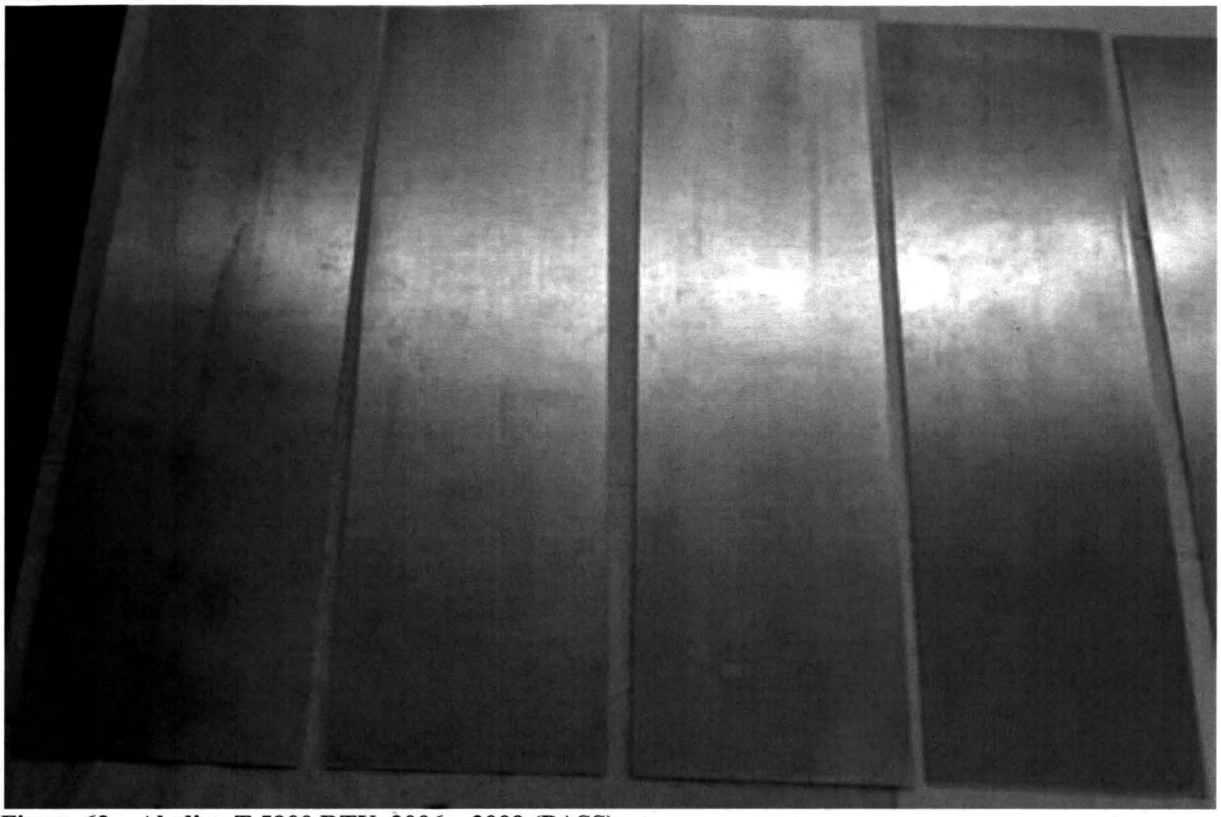

Figure 62 – Alodine T 5900 RTU, 2006 – 2009 (PASS)

Figure 63 - Alodine T 5900 RTU, 2051 – 2055 (FAIL)

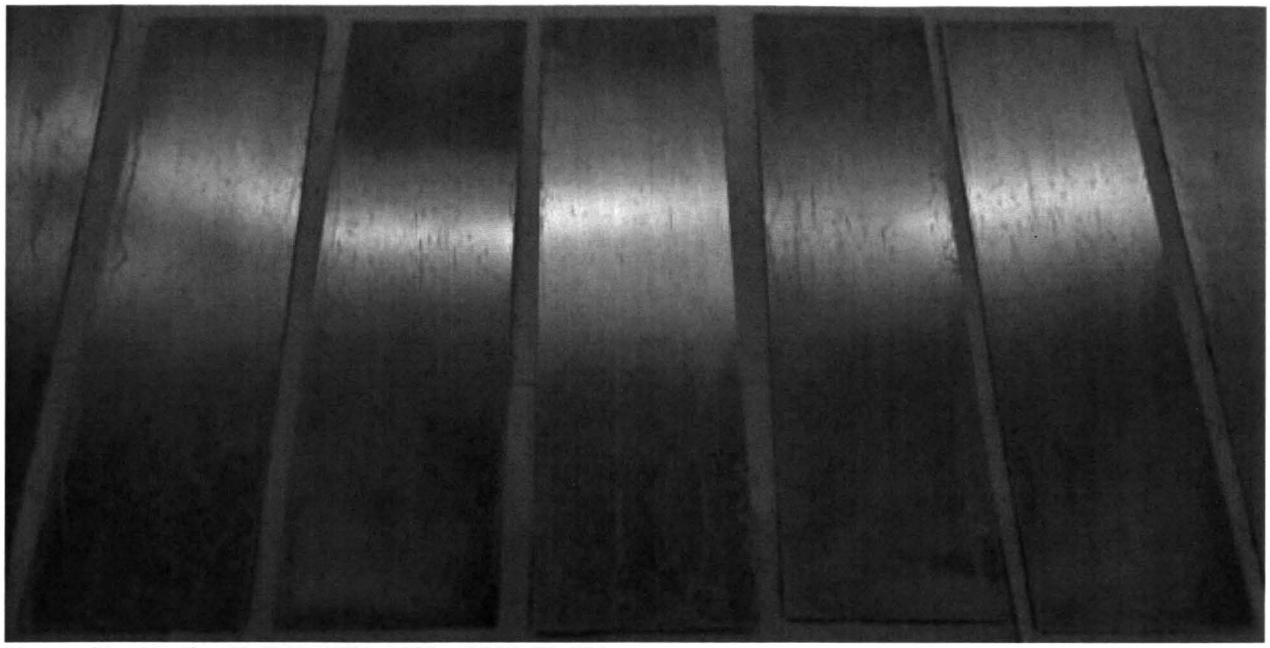

Figure 64 - Alodine T 5900 RTU, 2089 – 2093 (FAIL)

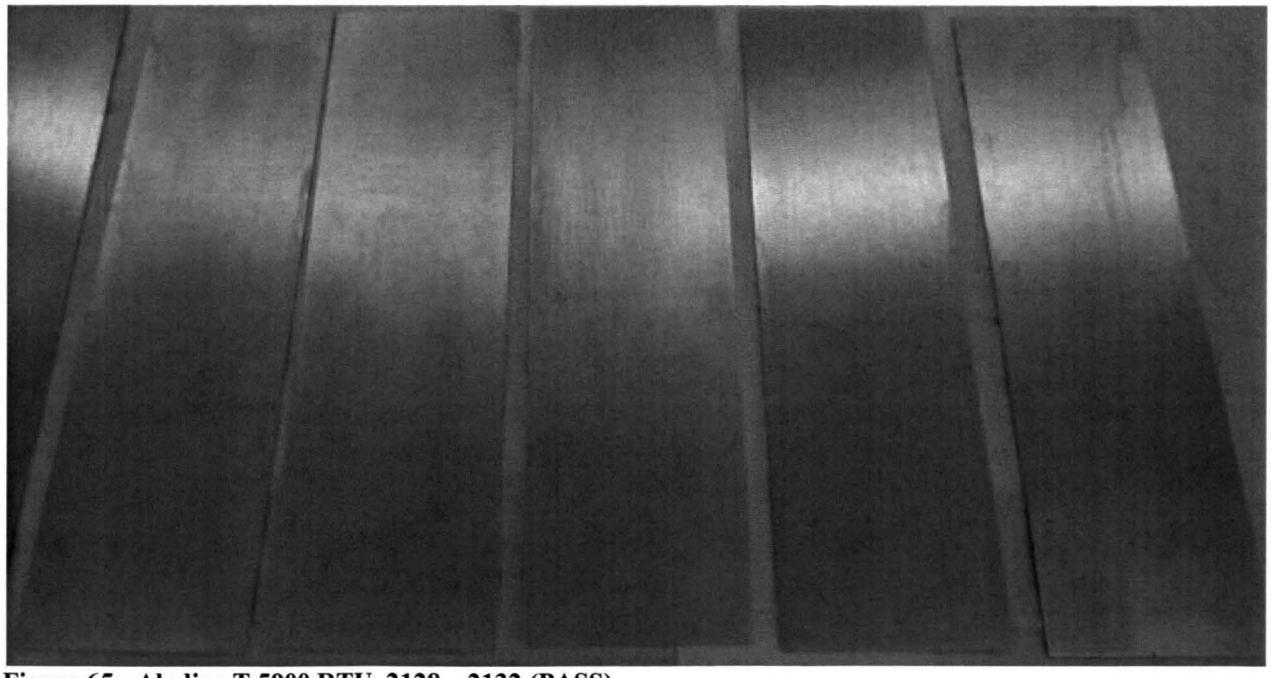

Figure 65 - Alodine T 5900 RTU, 2128 – 2132 (PASS)

Iridite NCP

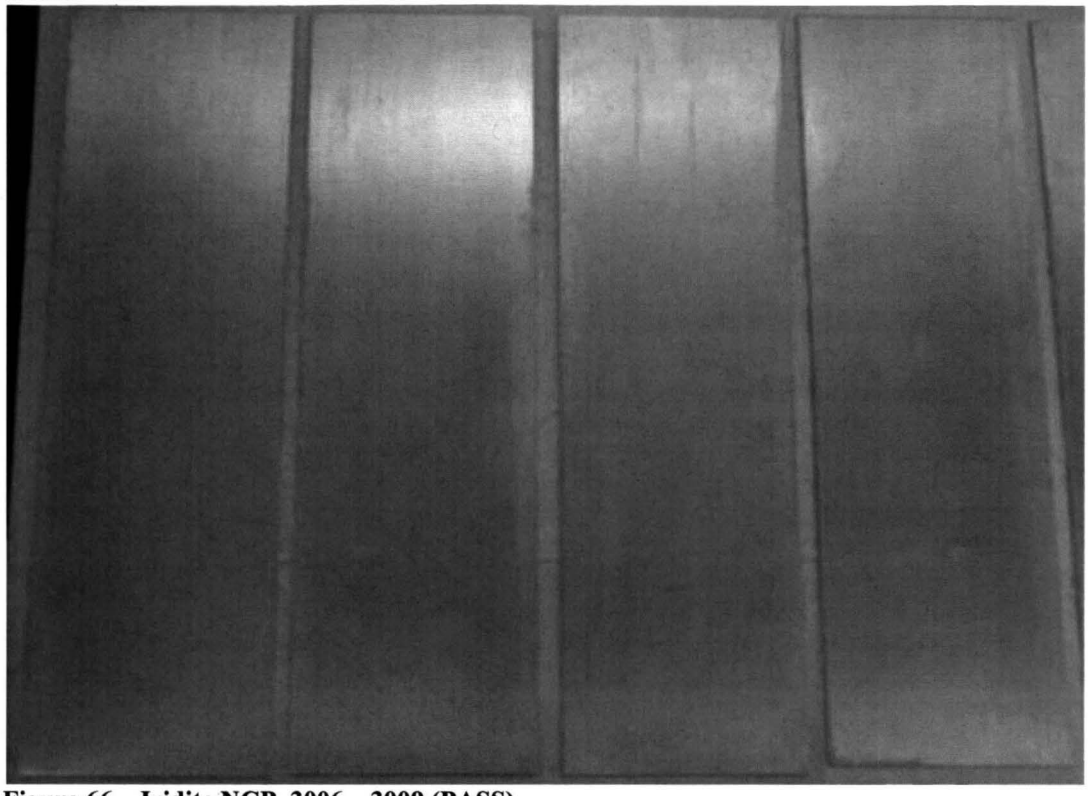

Figure 66 – Iridite NCP, 3006 – 3009 (PASS)

Figure 67 – Iridite NCP, 3051 – 3055 (FAIL)

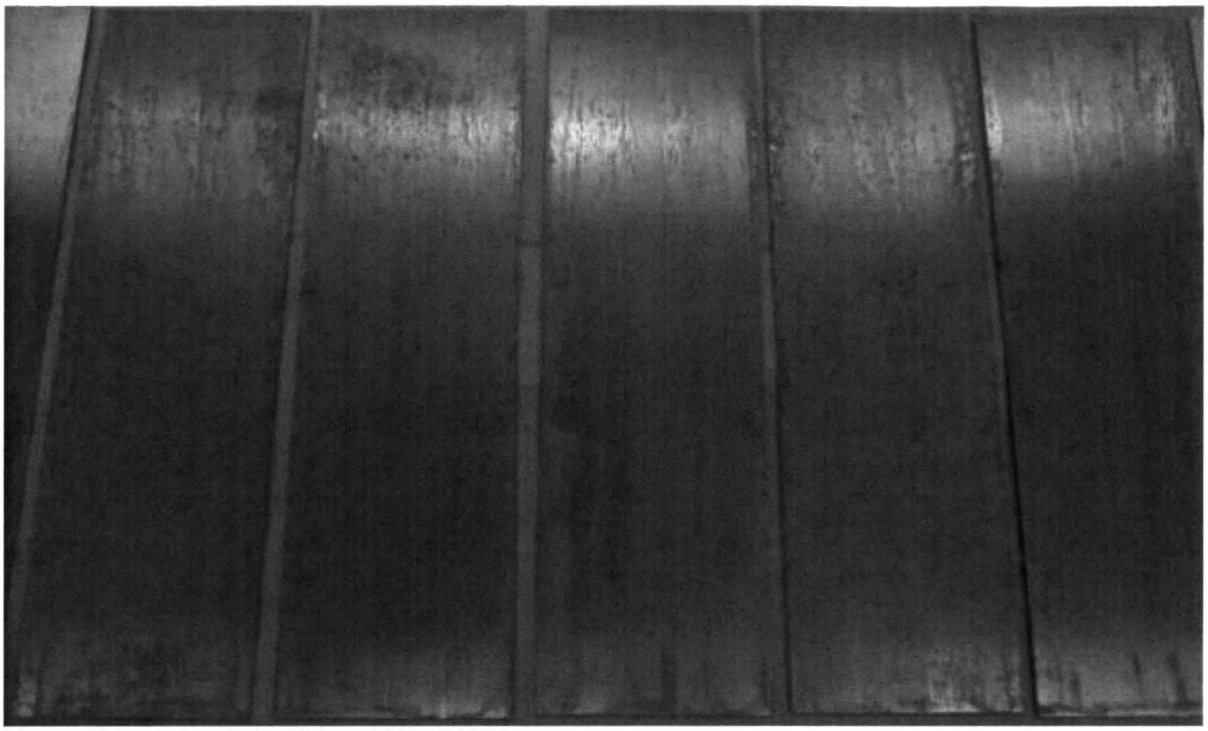

Figure 68 – Iridite NCP, 3089 – 3093 (FAIL)

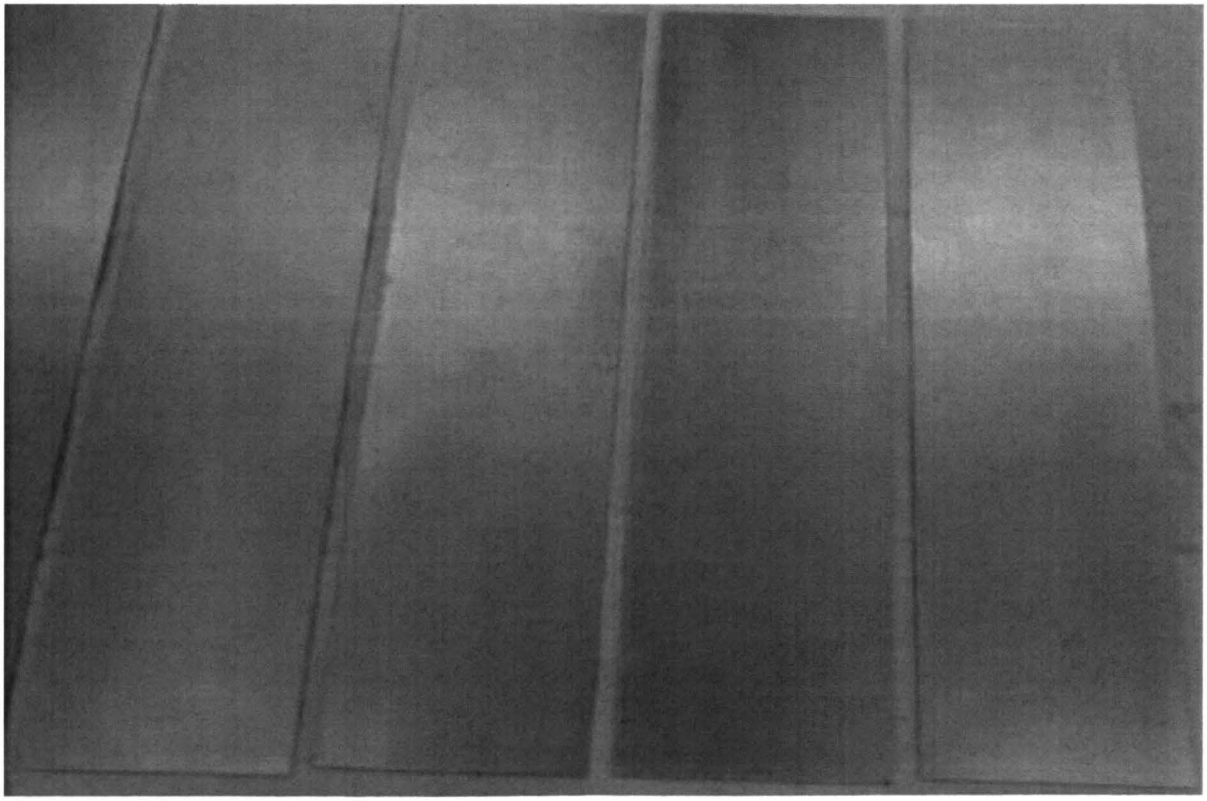

Figure 69 – Iridite NCP, 3129 – 3132 (PASS)

Metalast HF

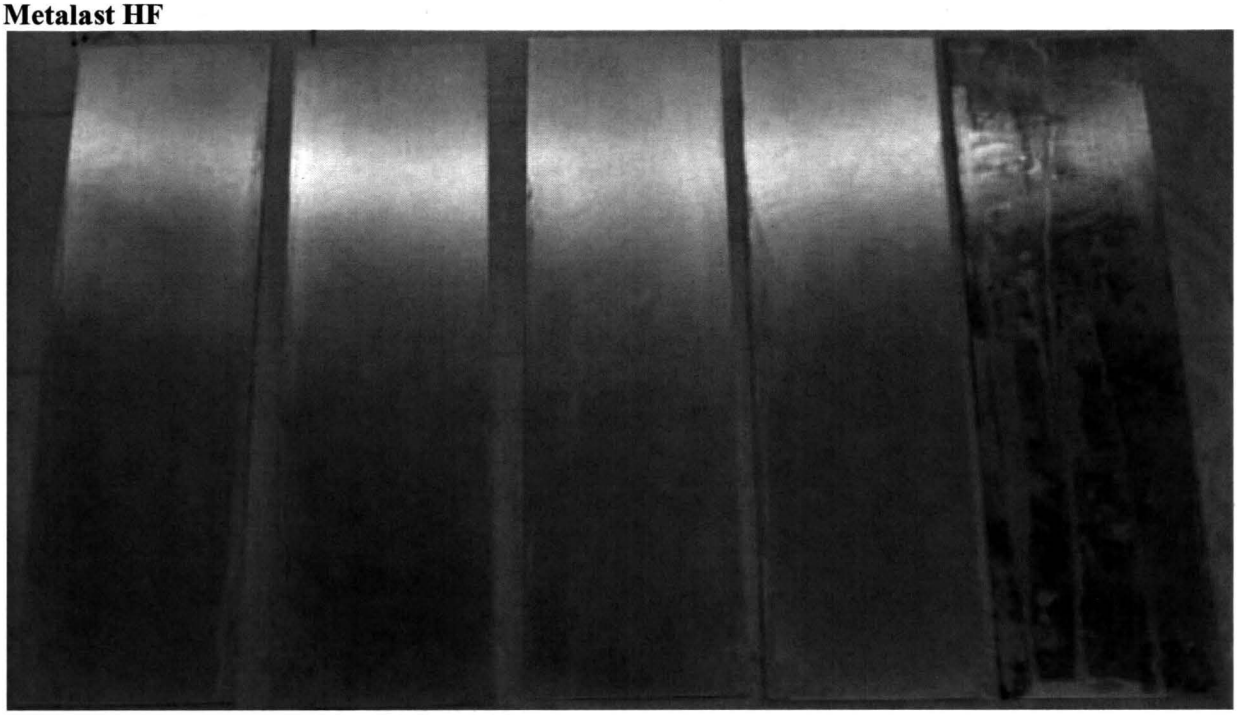

Figure 70 – Metalast HF, 4006 – 4010 (PASS)

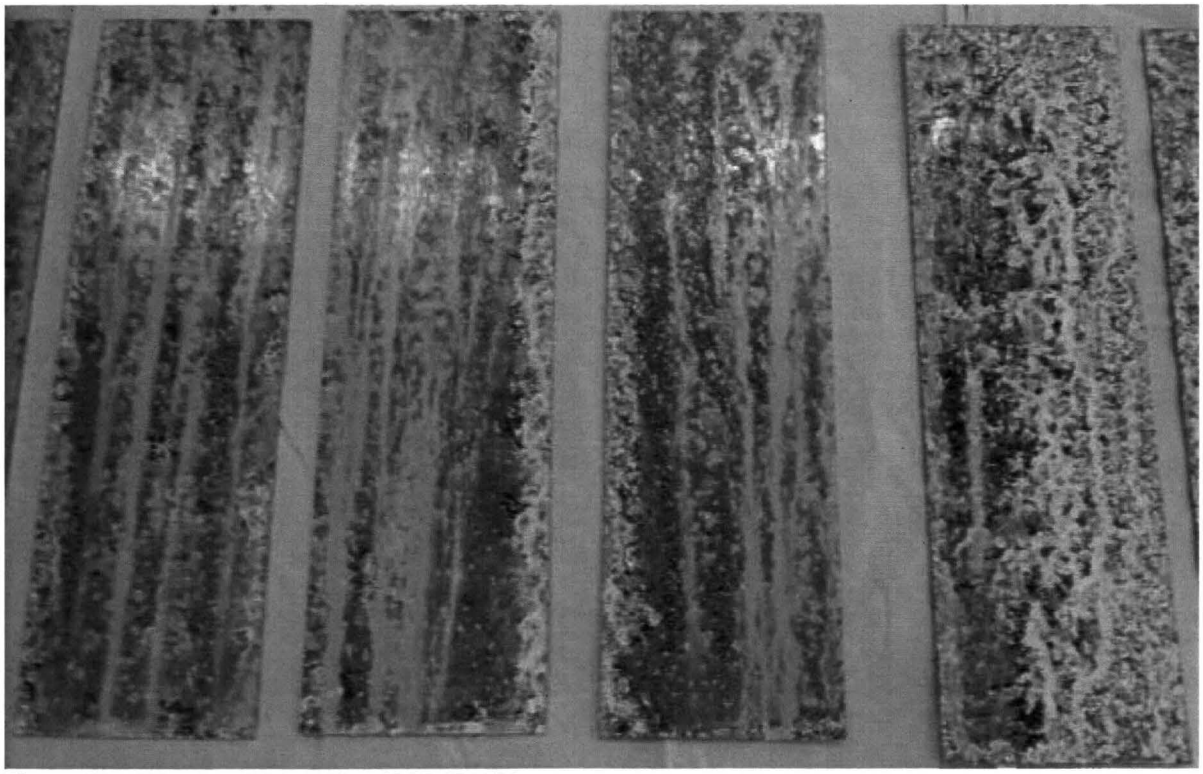

Figure 71 – Metalast HF, 4052 – 4055 (FAIL)

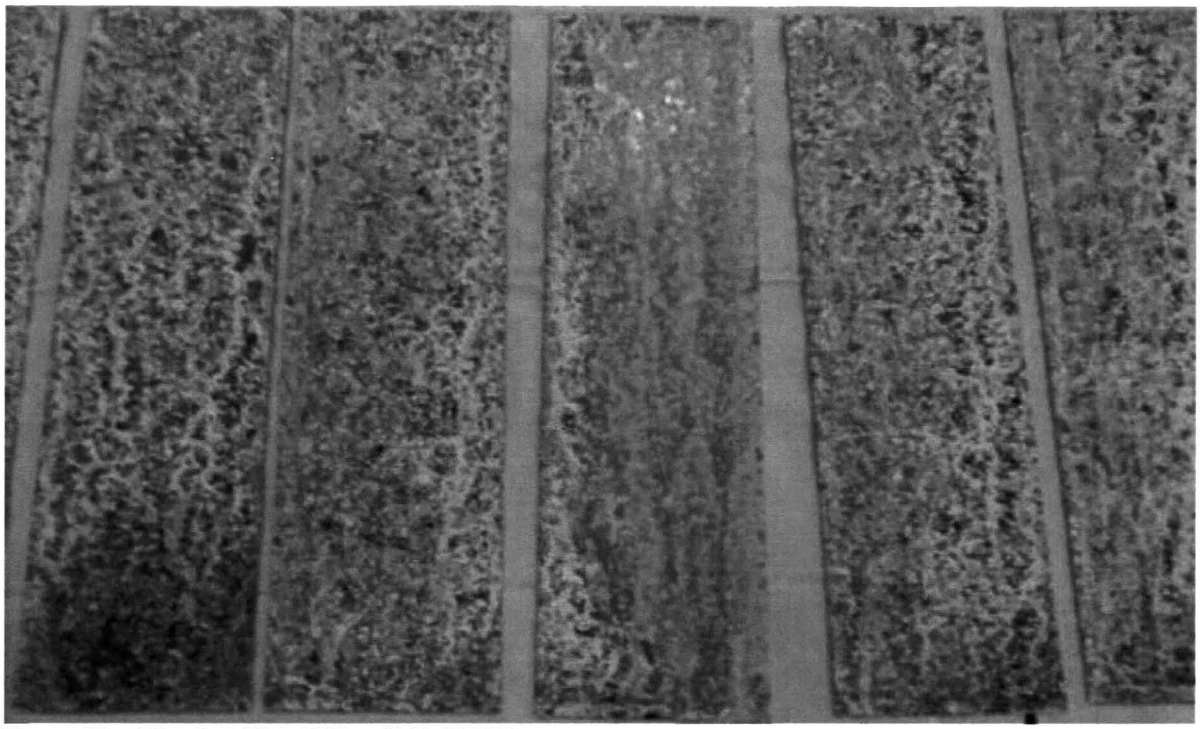

Figure 72 – Metalast HF, 4089 – 4093 (FAIL)

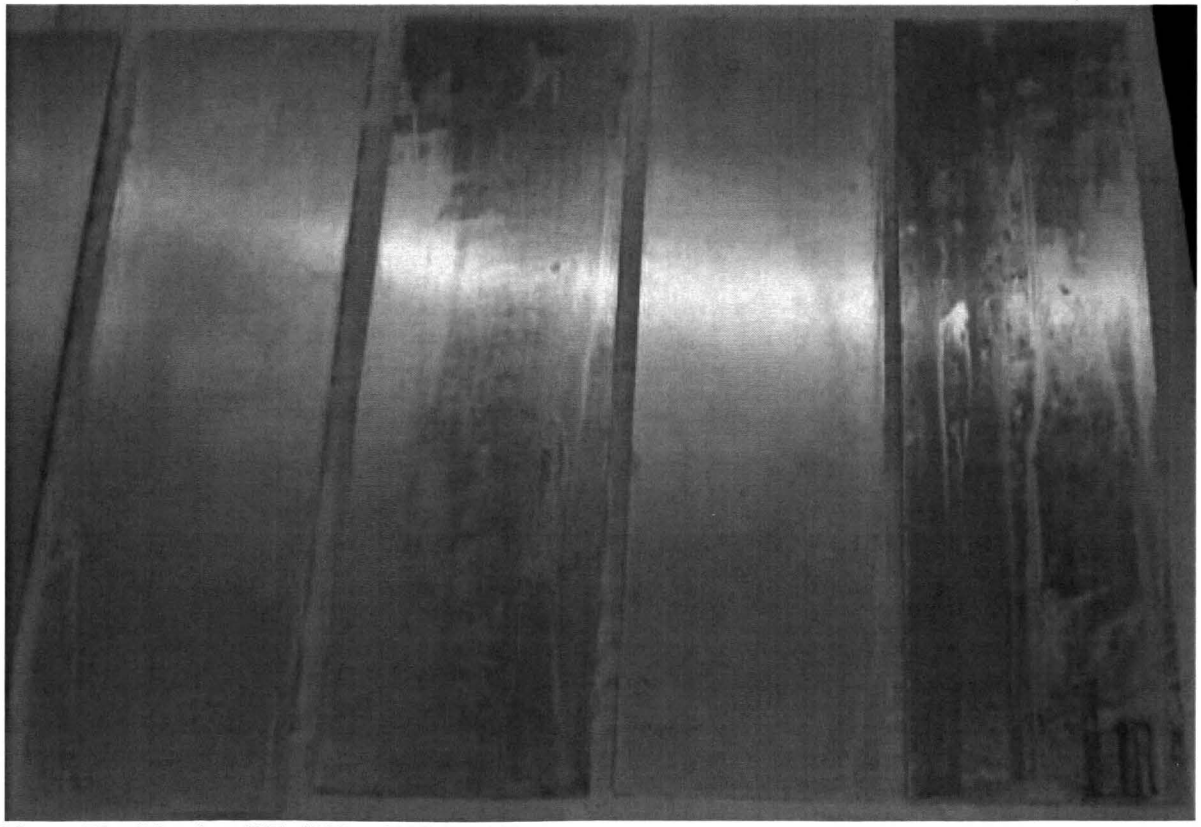

Figure 73 – Metalast HF, 4129 – 4132 (PASS)

Metalast HF-EPA

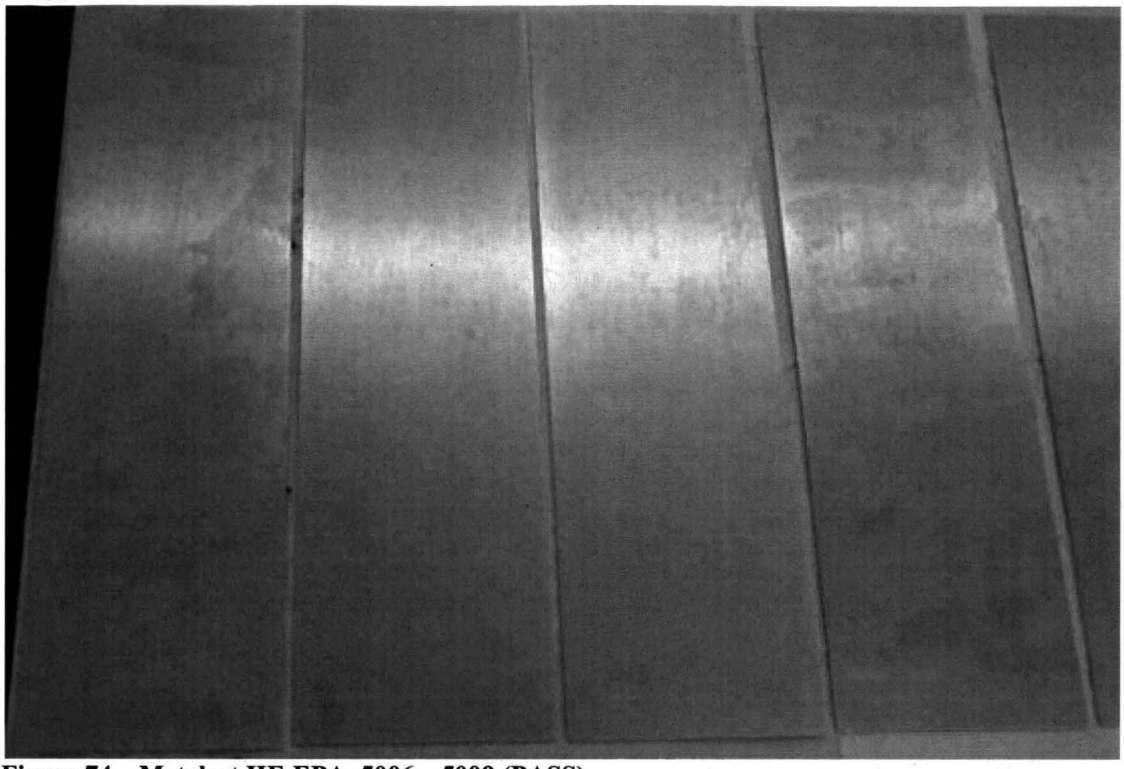

Figure 74 – Metalast HF-EPA, 5006 – 5009 (PASS)

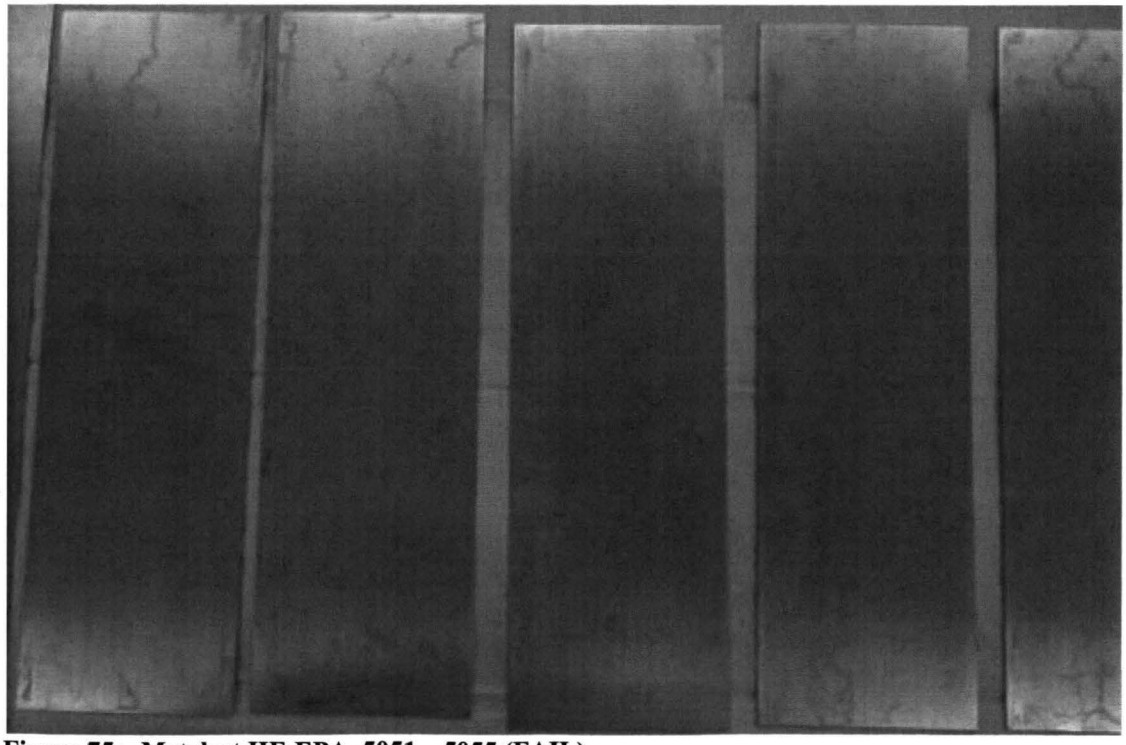

Figure 75 – Metalast HF-EPA, 5051 – 5055 (FAIL)

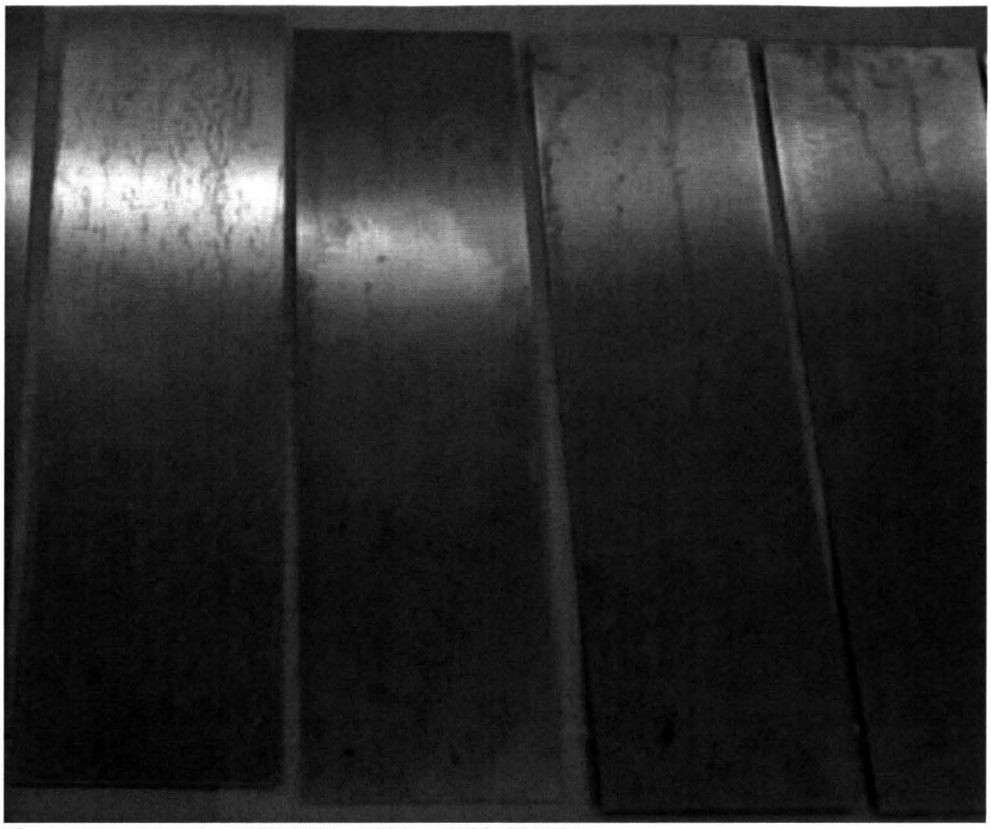

Figure 76 – Metalast HF-EPA, 5089 – 5092 (FAIL)

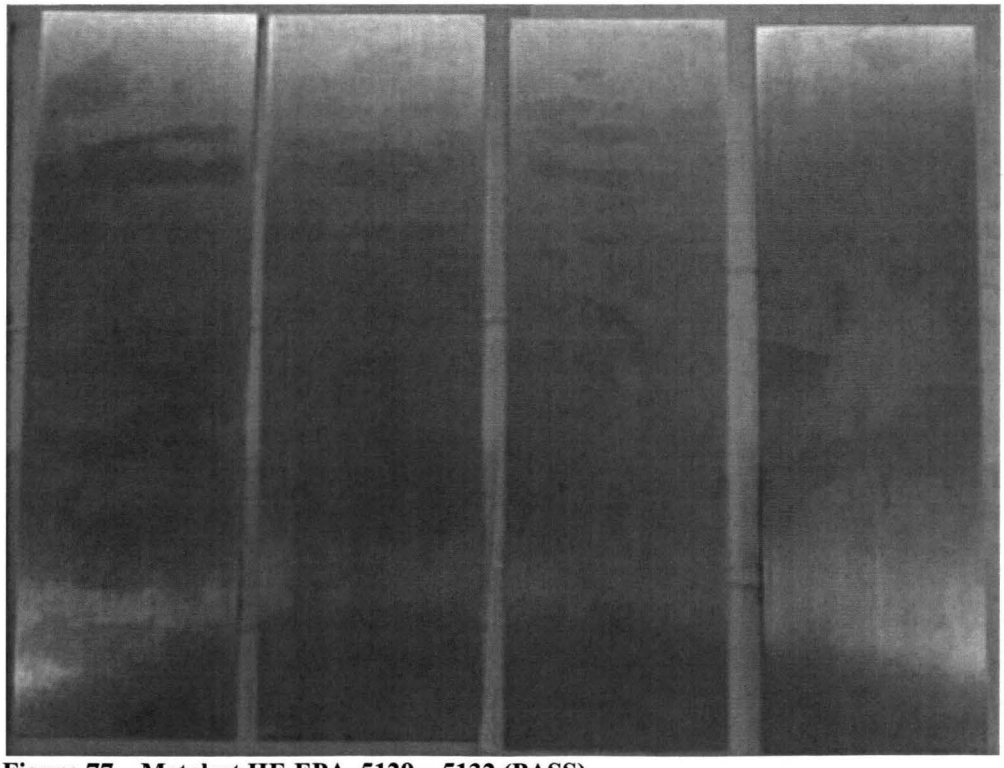

Figure 77 – Metalast HF-EPA, 5129 – 5132 (PASS)

SurTec 650

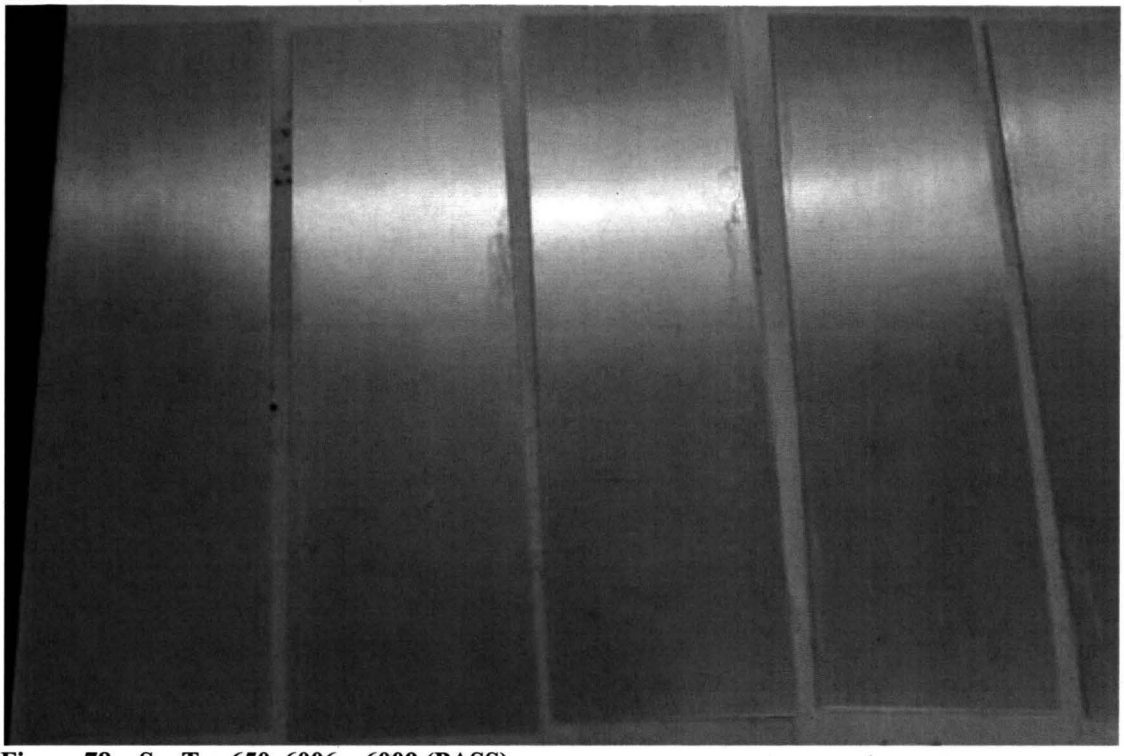

Figure 78 – SurTec 650, 6006 – 6009 (PASS)

Figure 79 – SurTec 650, 6052 – 6055 (FAIL)

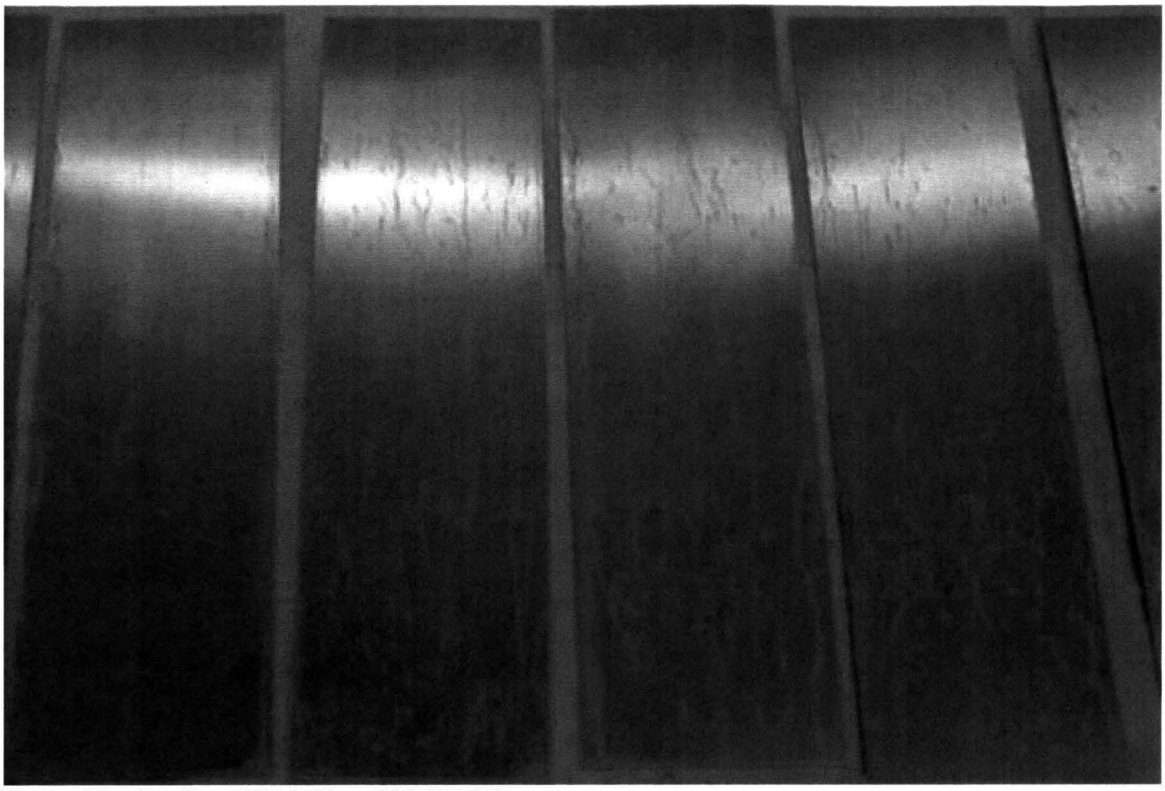

Figure 80 – SurTec 650, 6089 – 6092 (FAIL)

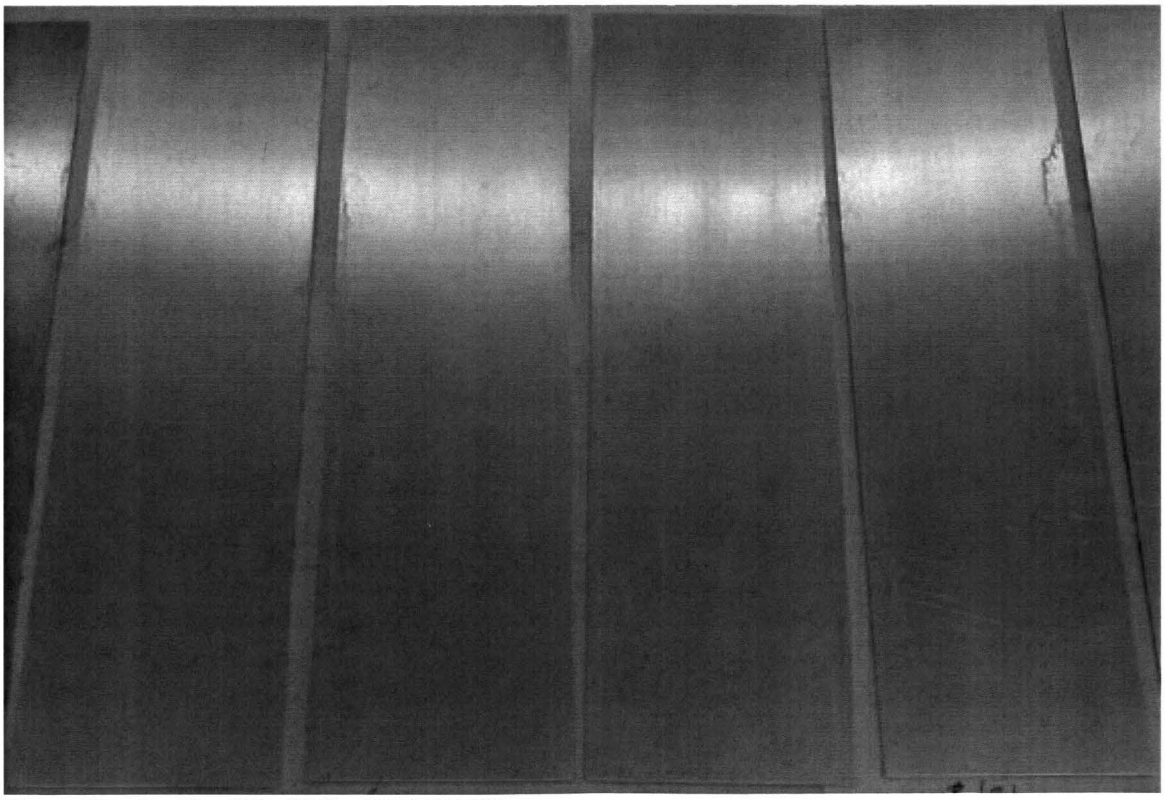

Figure 81 – SurTec 650, 6128 – 6131 (PASS)

SurTec 650C

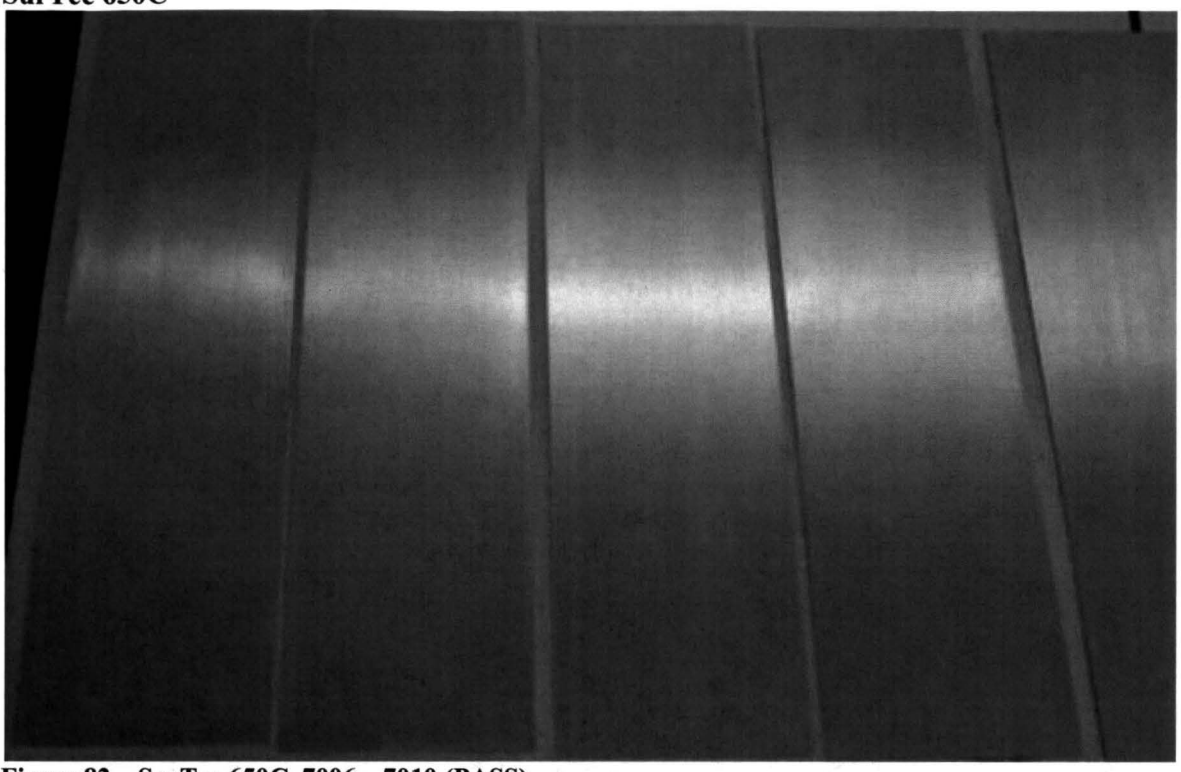

Figure 82 – SurTec 650C, 7006 – 7010 (PASS)

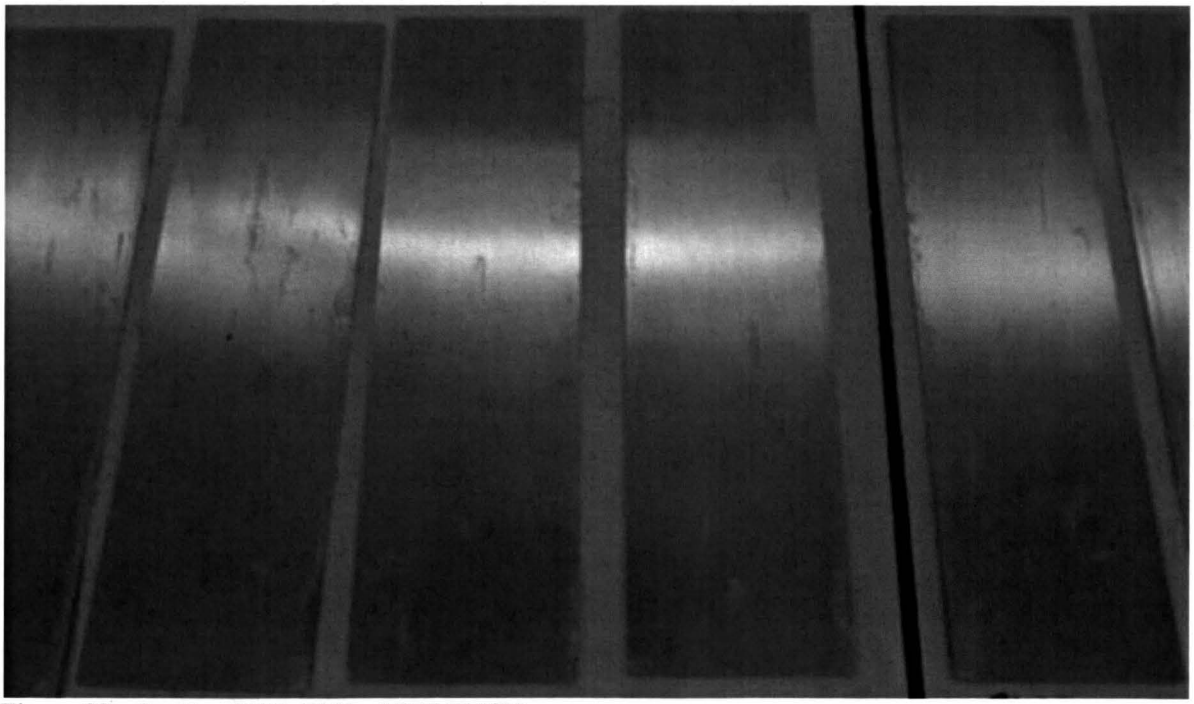

Figure 83 – SurTec 650C, 7051 – 7055 (FAIL)

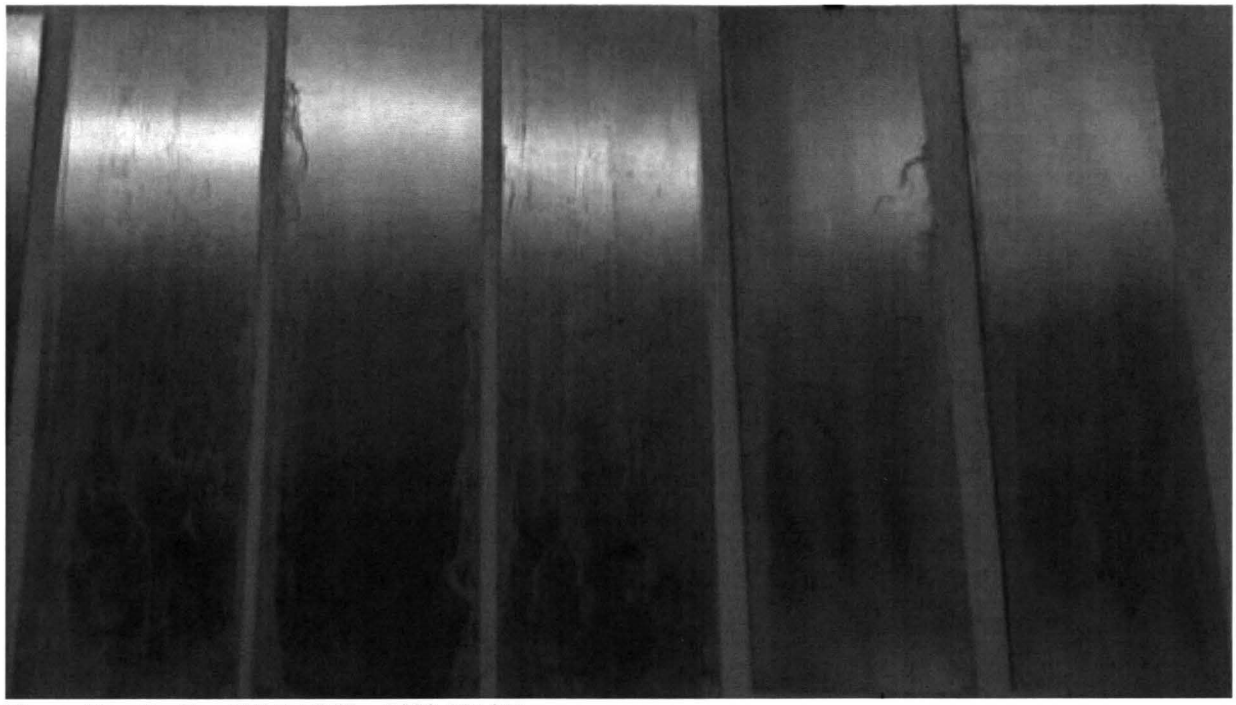

Figure 84 – SurTec 650C, 7089 – 7093 (FAIL)

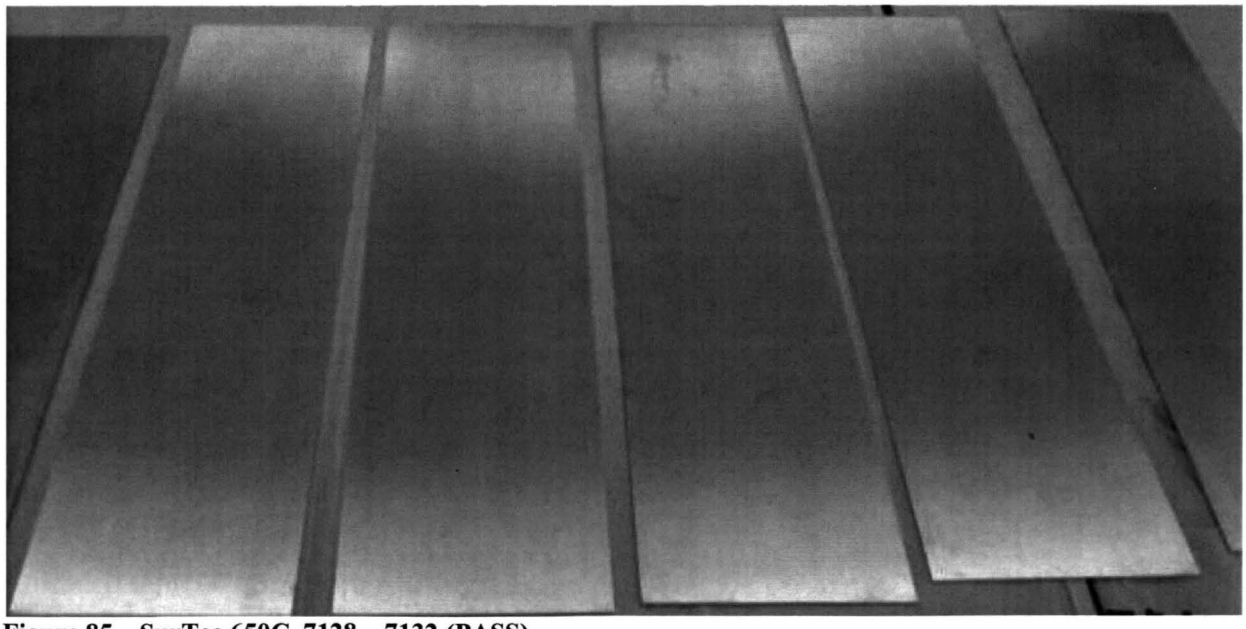

Figure 85 – SurTec 650C, 7128 – 7132 (PASS)

Appendix B –
Panel Photographs - ASTM B-117; Failure

Alodine 1600

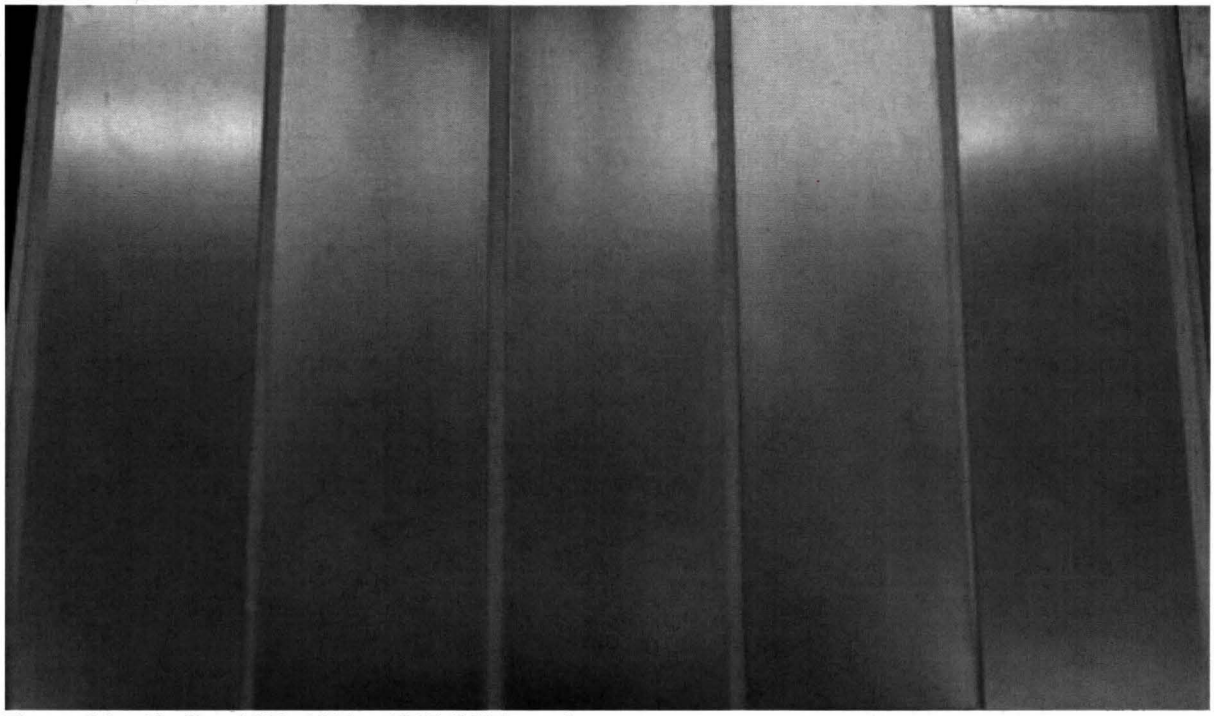

Figure 86 – Alodine 1600, 1011 – 1015 (168 hours)

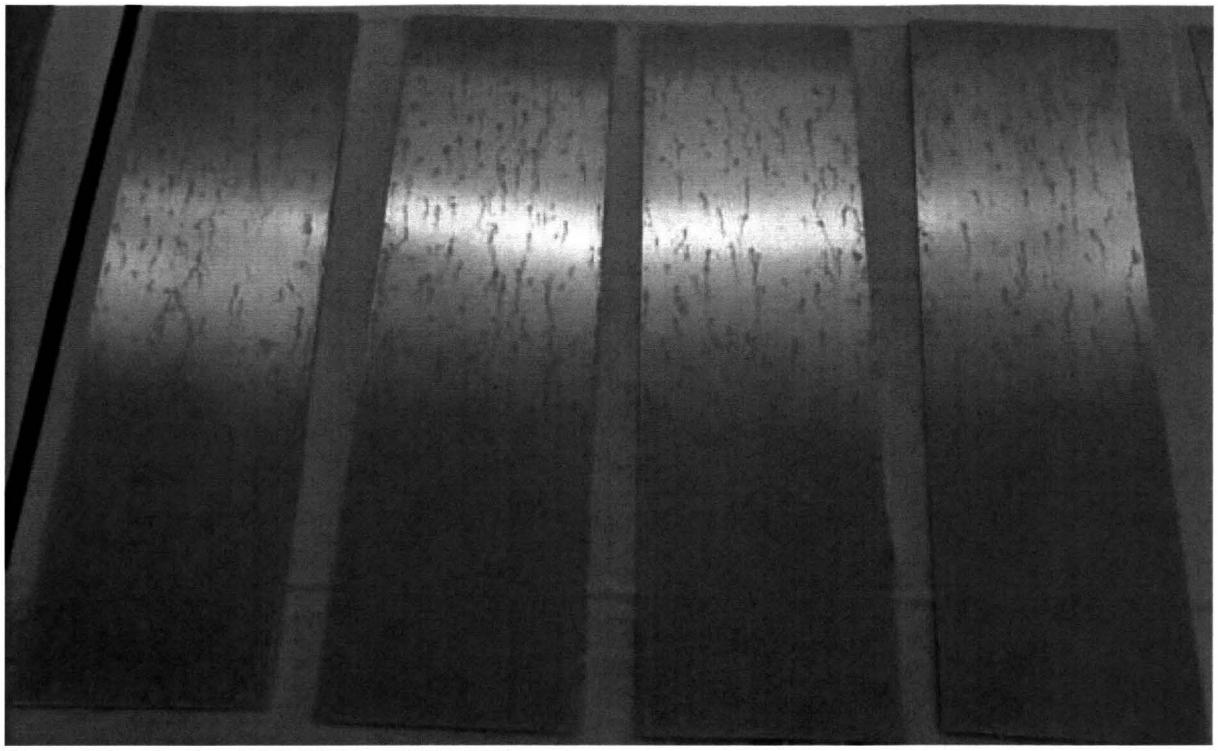

Figure 87 – Alodine 1600, 1056 – 1059 (168 hours)

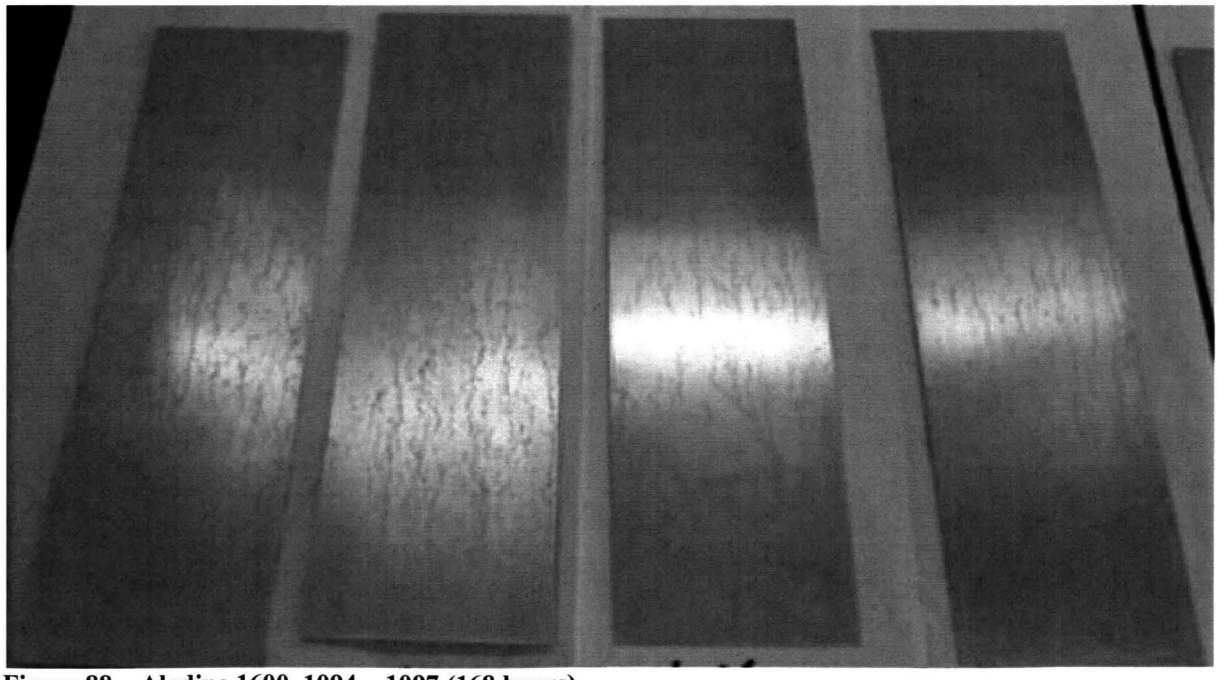

Figure 88 – Alodine 1600, 1094 – 1097 (168 hours)

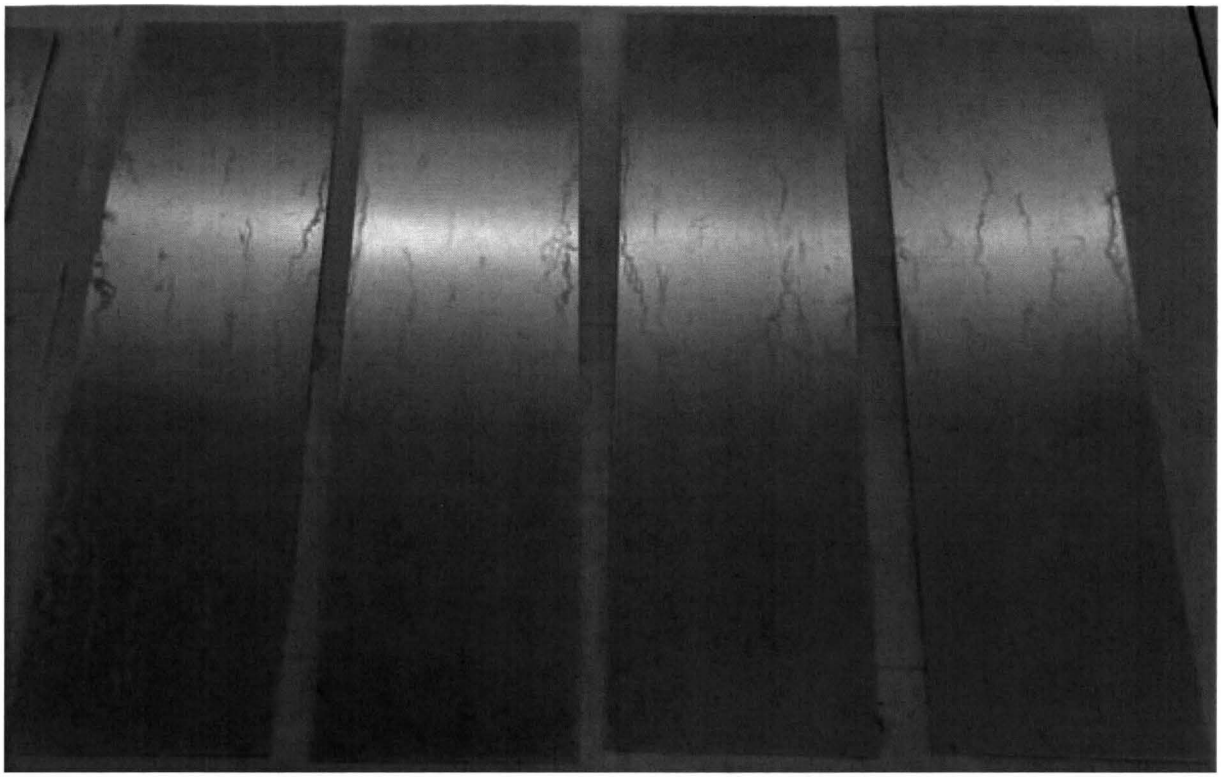

Figure 89 – Alodine 1600, 1133 - 1136 (168 hours)

Alodine T 5900 RTU

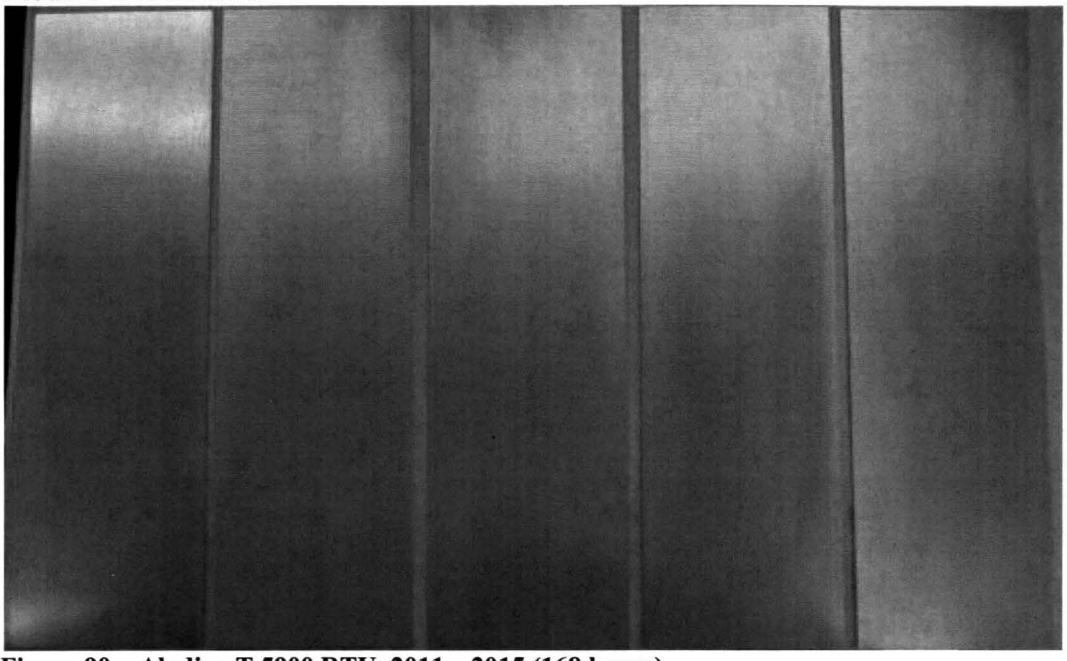

Figure 90 – Alodine T 5900 RTU, 2011 – 2015 (168 hours)

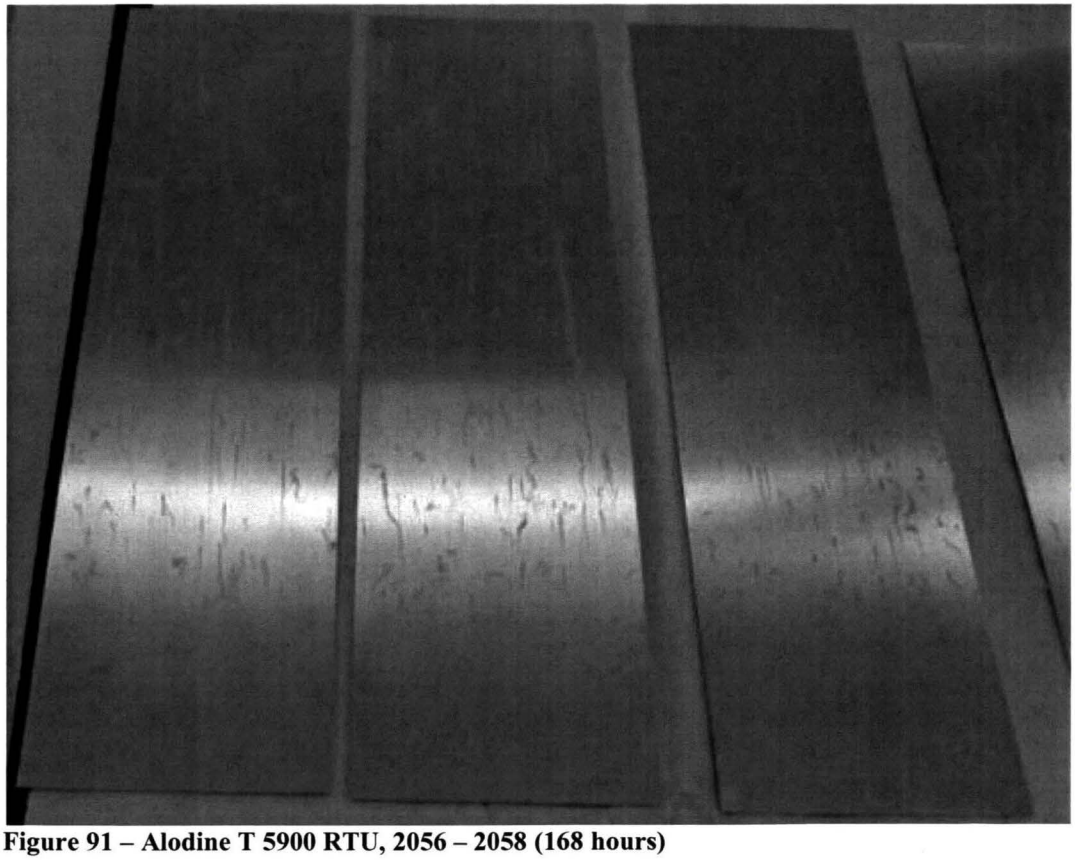

Figure 91 – Alodine T 5900 RTU, 2056 – 2058 (168 hours)

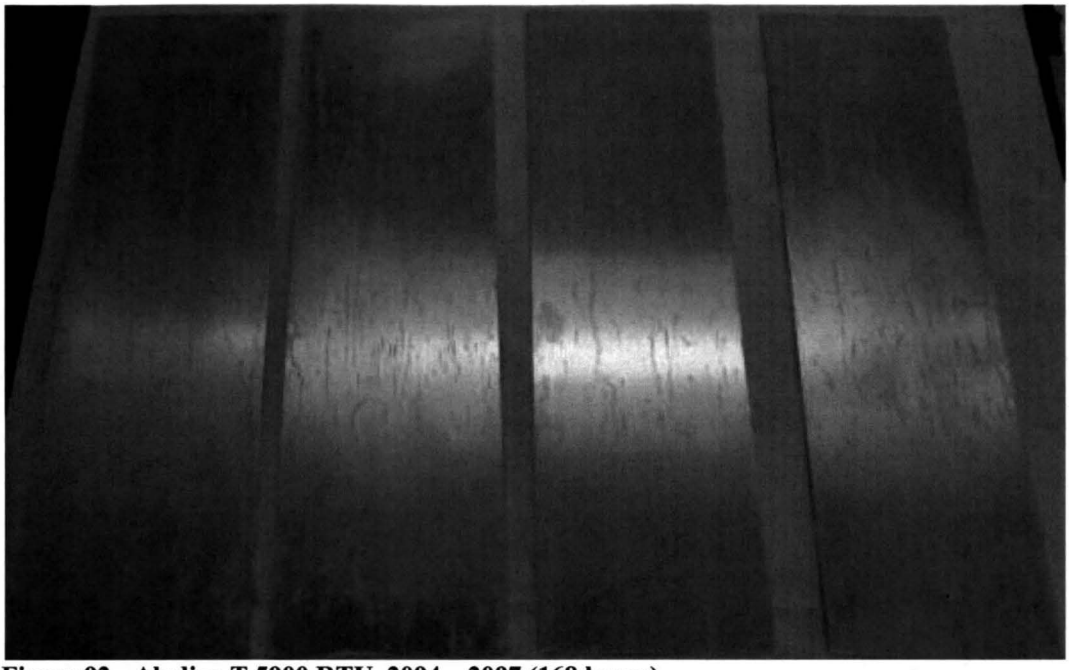

Figure 92 - Alodine T 5900 RTU, 2094 – 2097 (168 hours)

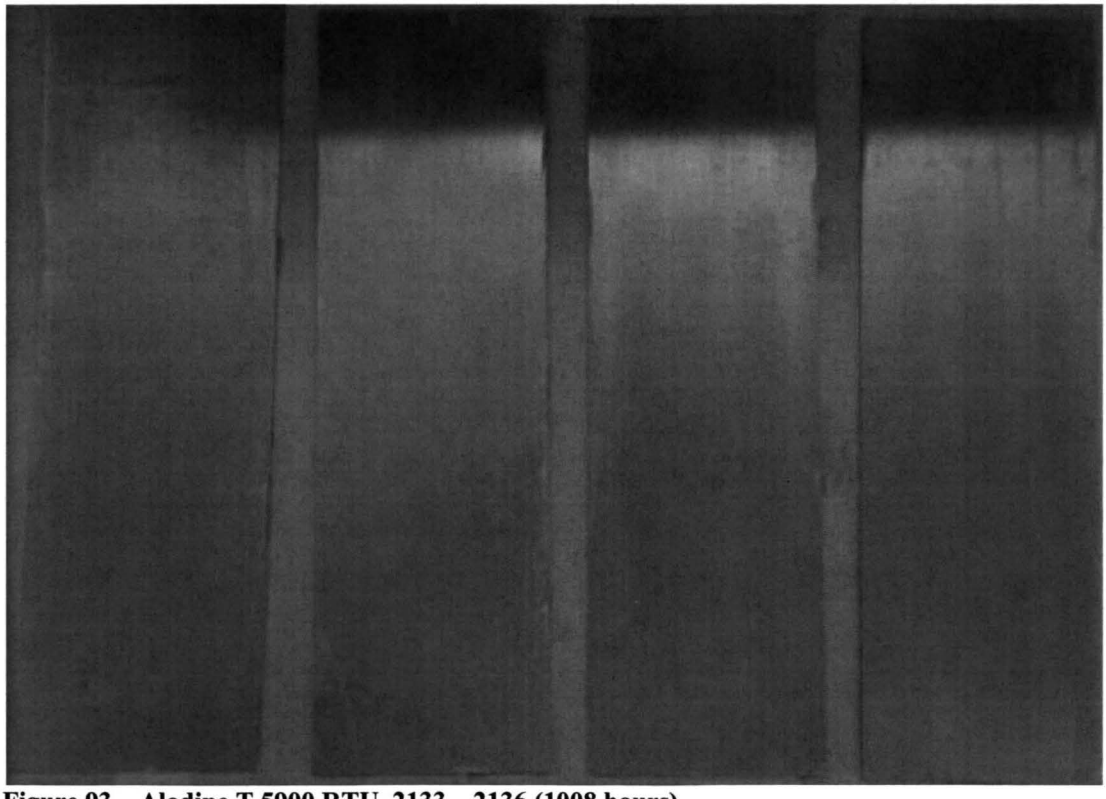

Figure 93 – Alodine T 5900 RTU, 2133 – 2136 (1008 hours)

Iridite NCP

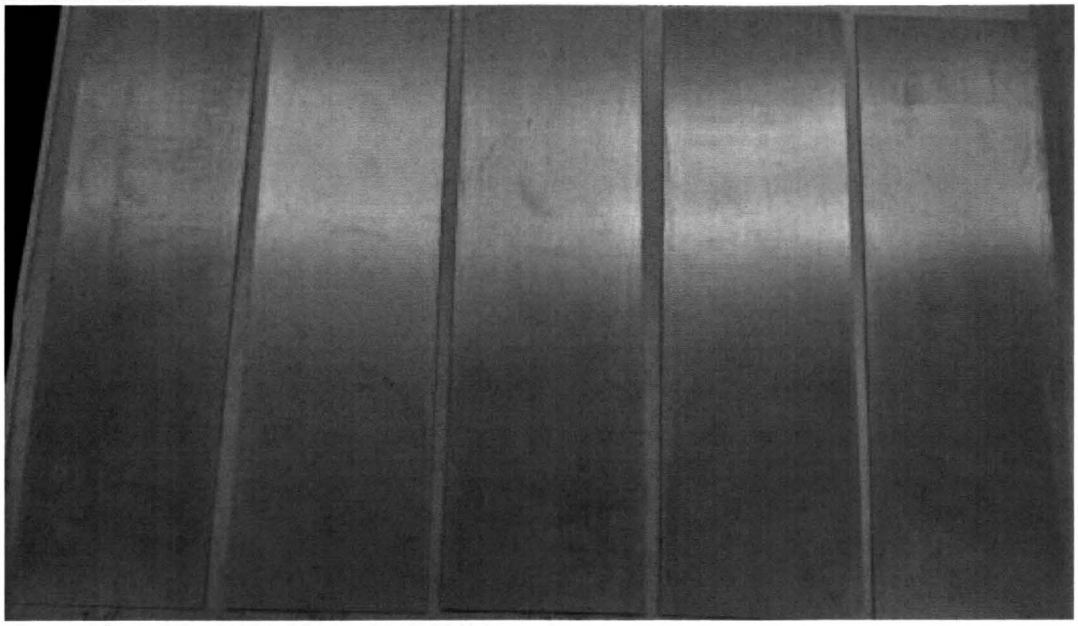

Figure 94 – Iridite NCP, 3011 – 3015 (168 hours)

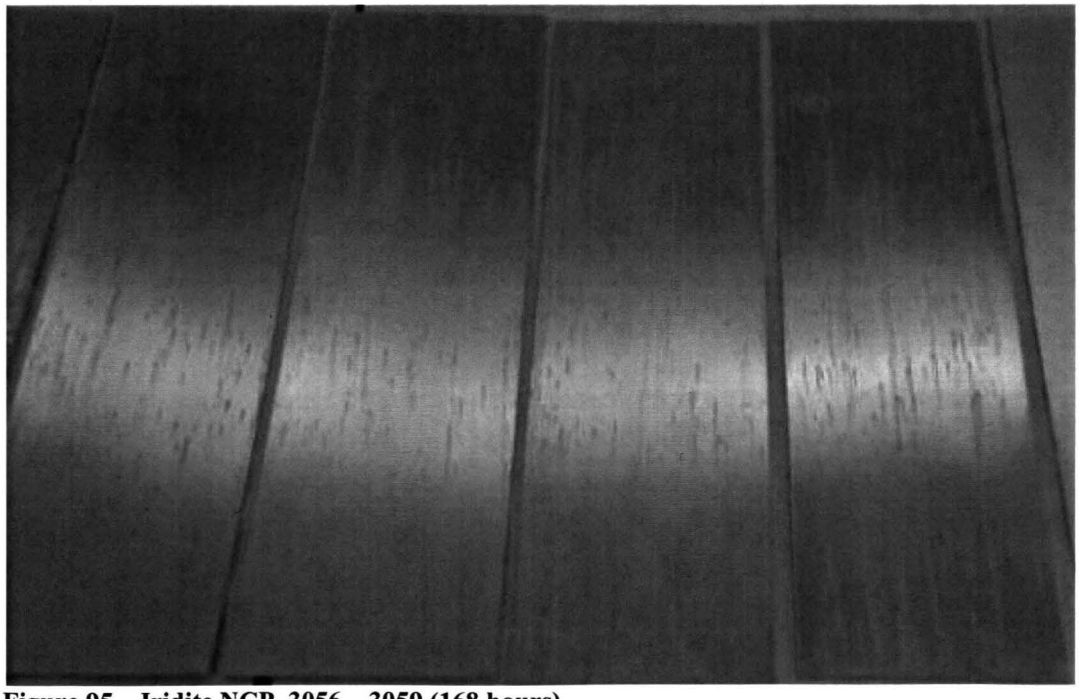

Figure 95 – Iridite NCP, 3056 – 3059 (168 hours)

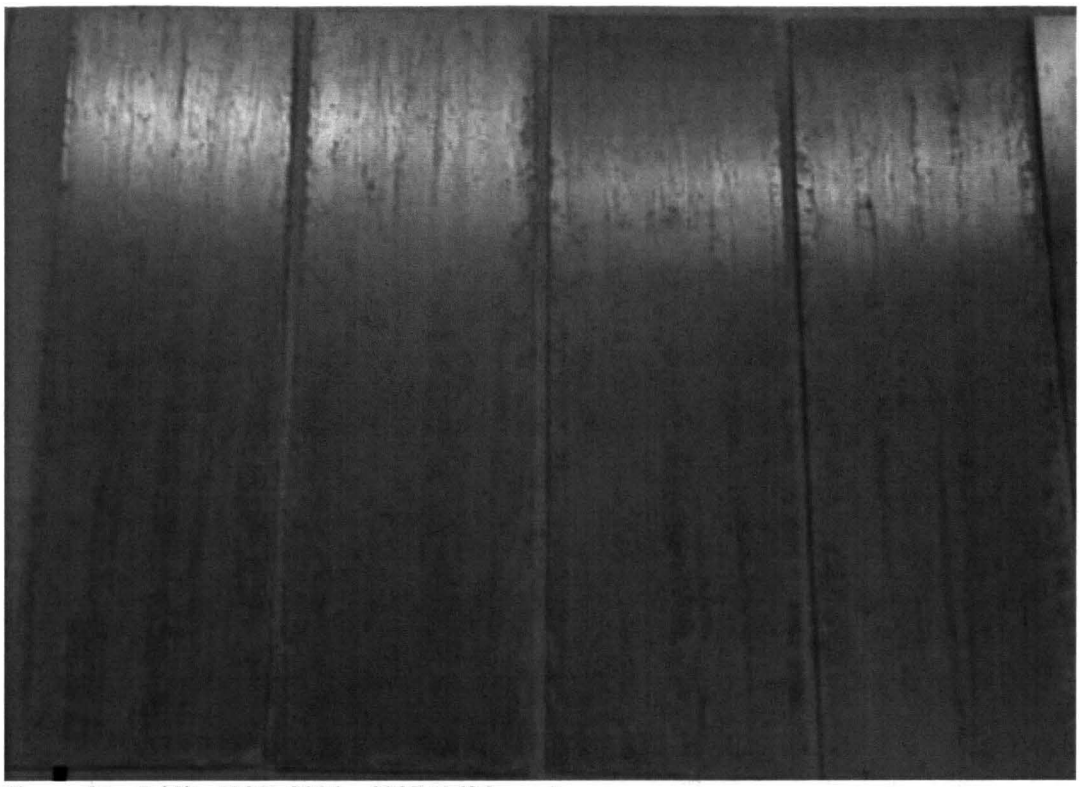

Figure 96 – Iridite NCP, 3094 – 3097 (168 hours)

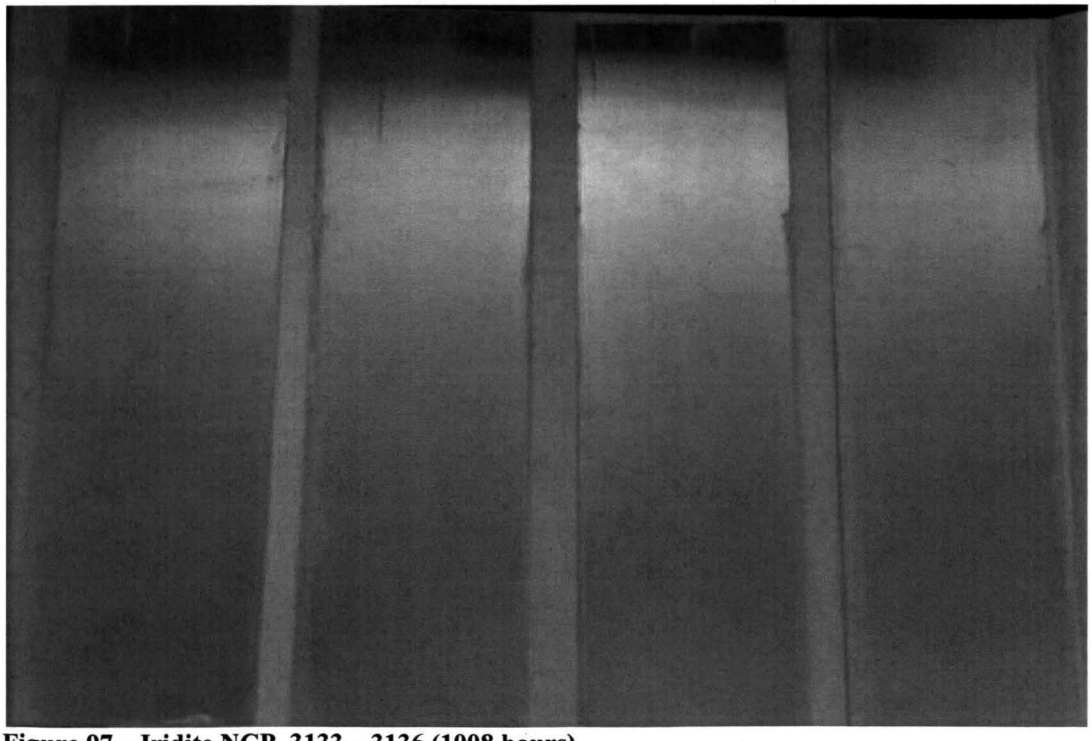

Figure 97 – Iridite NCP, 3133 – 3136 (1008 hours)

Metalast HF

Figure 98 – Metalast HF, 4011 – 4015 (168 hours)

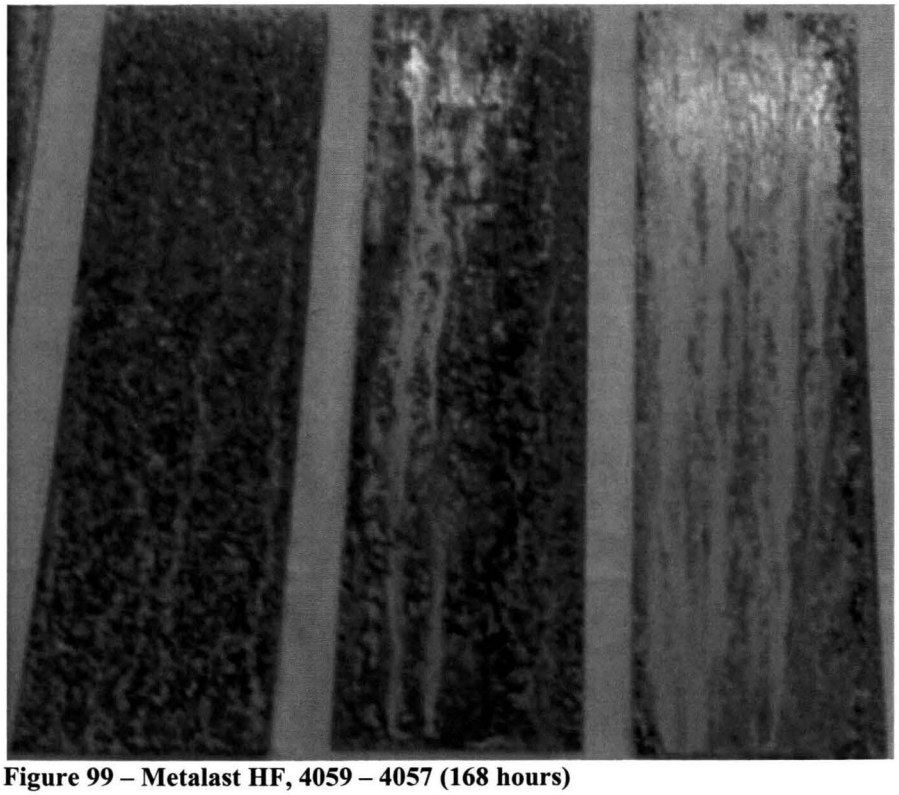

Figure 99 – Metalast HF, 4059 – 4057 (168 hours)

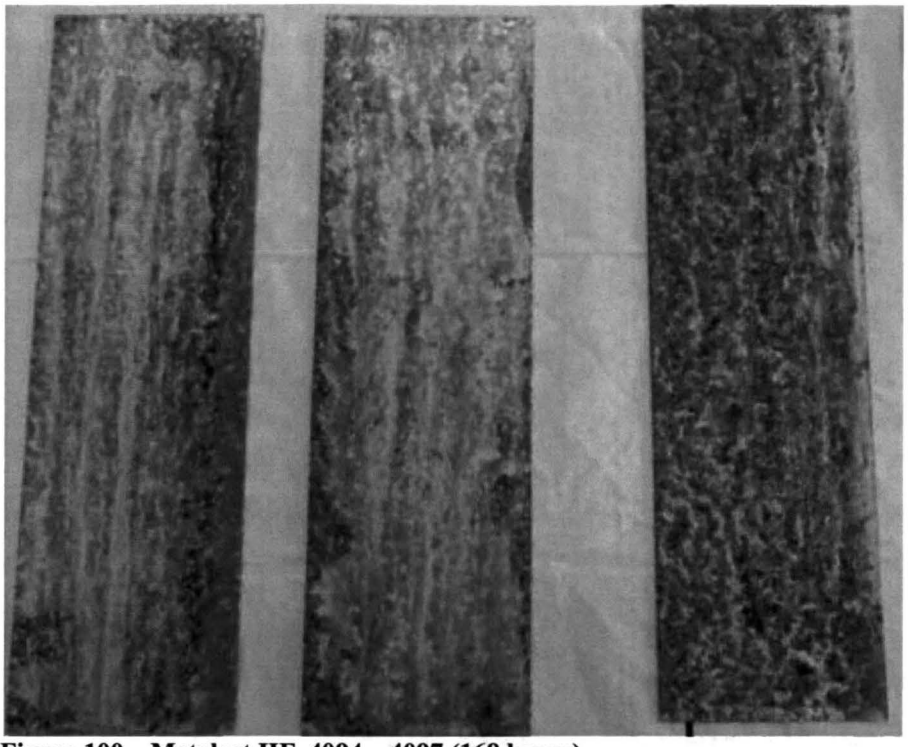

Figure 100 – Metalast HF, 4094 – 4097 (168 hours)

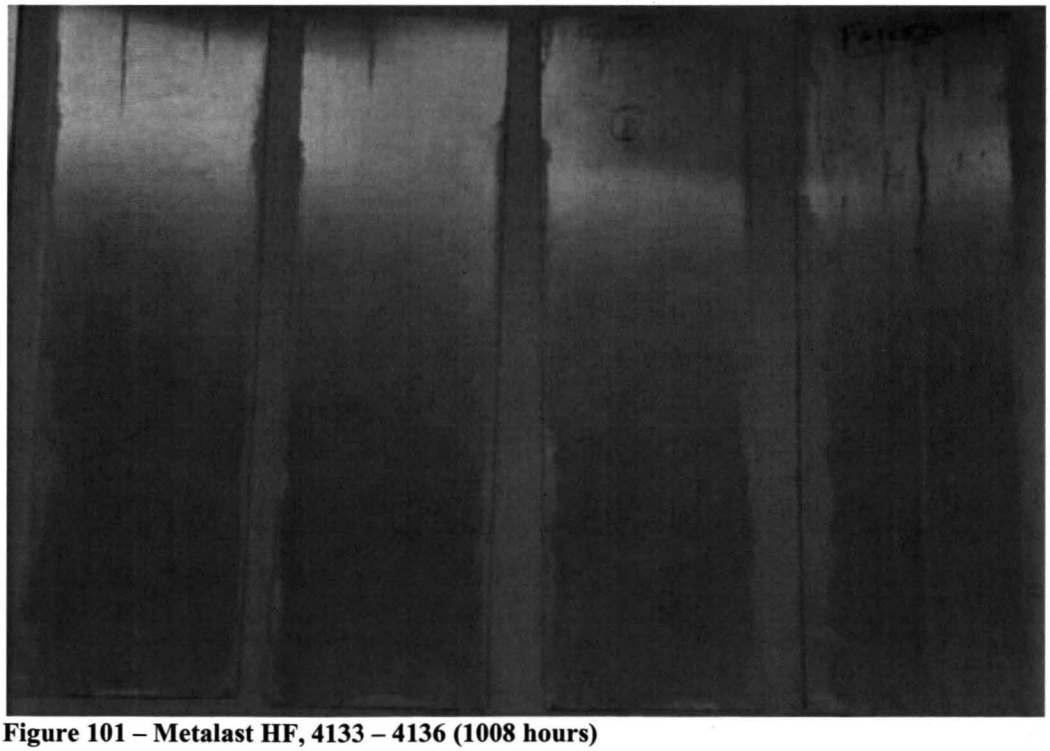

Figure 101 – Metalast HF, 4133 – 4136 (1008 hours)

Metalast HF-EPA

Figure 102 – Metalast HF-EPA, 5011 – 5015 (168 hours)

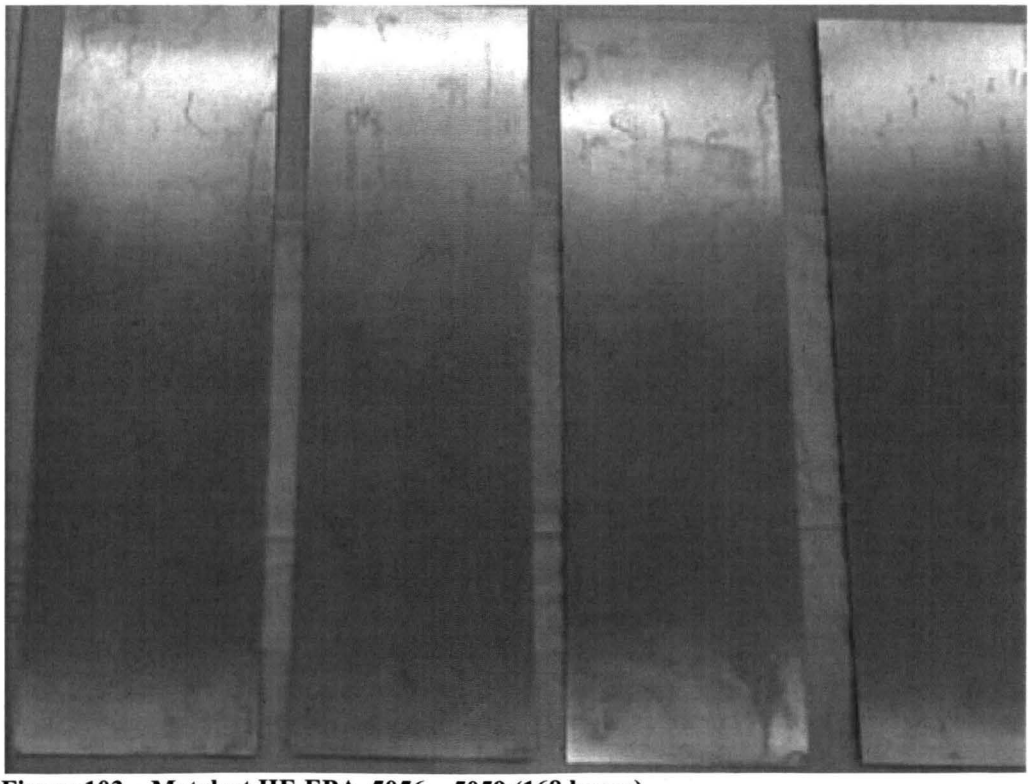

Figure 103 – Metalast HF-EPA, 5056 – 5059 (168 hours)

Figure 104 – Metalast HF-EPA, 5094 – 5097 (168 hours)

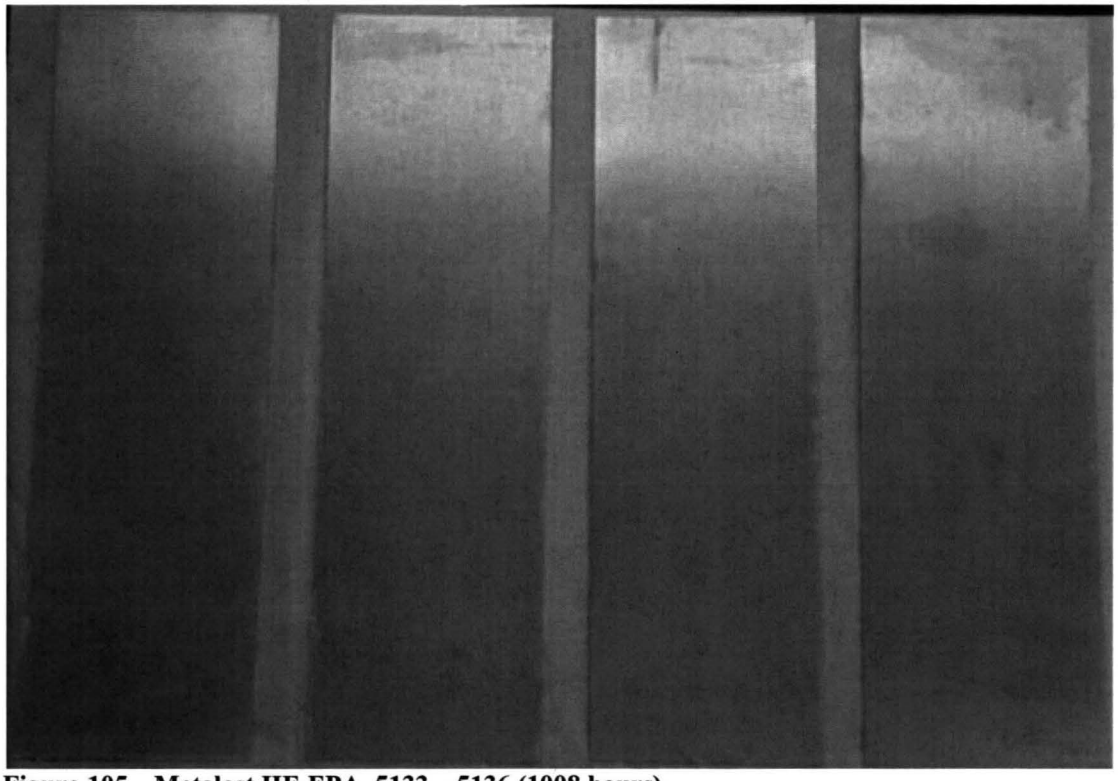

Figure 105 – Metalast HF-EPA, 5133 – 5136 (1008 hours)

SurTec 650

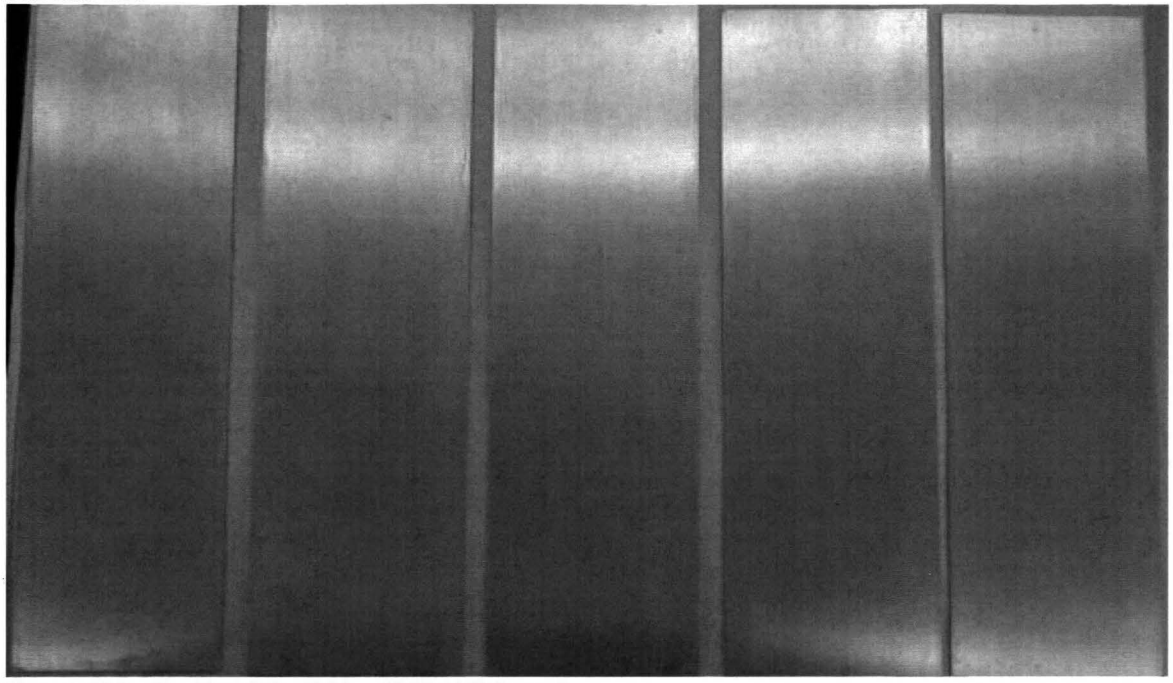

Figure 106 – SurTec 650, 6011 – 6015 (168 hours)

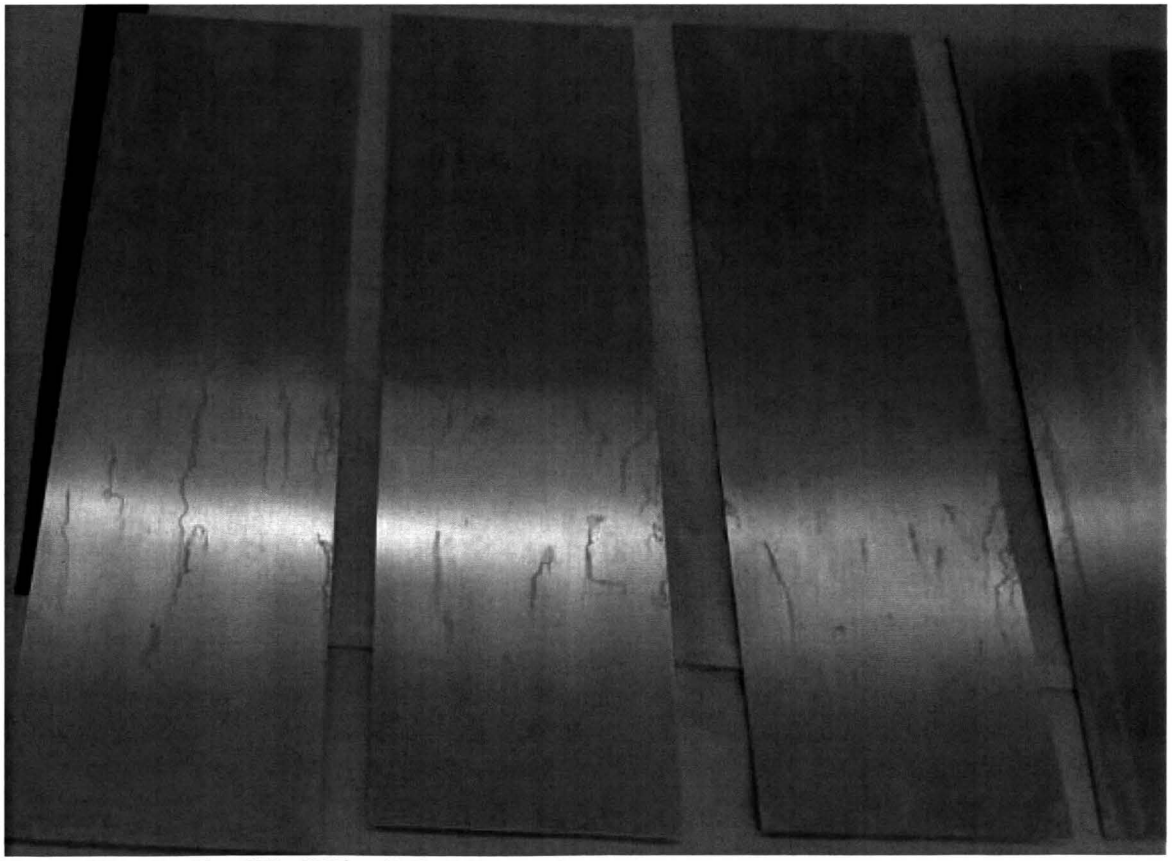

Figure 107 – SurTec 650, 6056 – 6058 (168 hours)

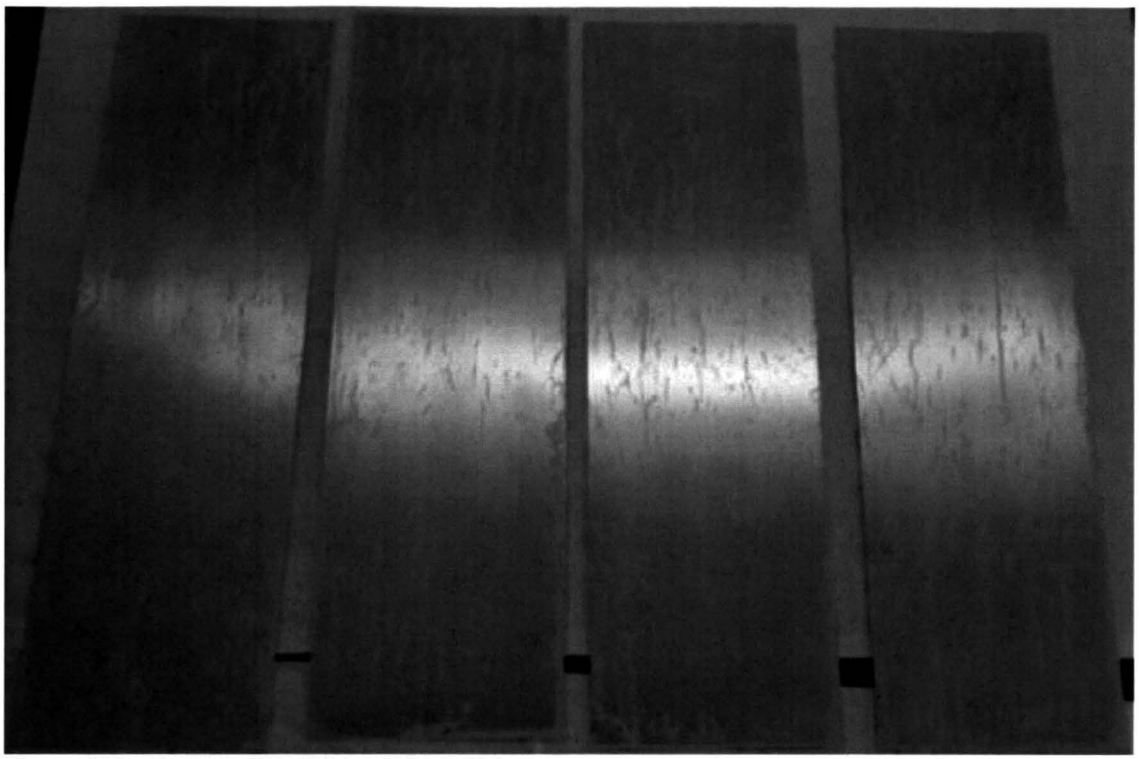

Figure 108 – SurTec 650, 6094 – 6097 (168 hours)

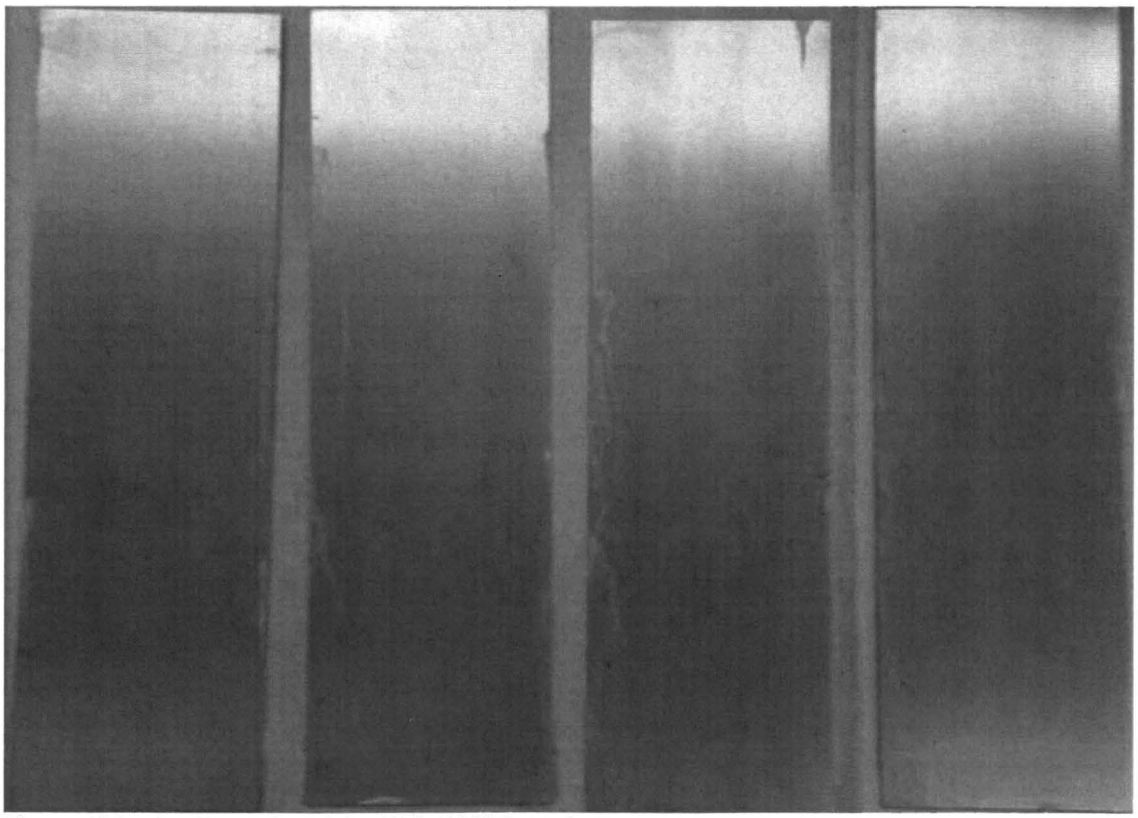

Figure 109 – SurTec 650, 6136 - 6133 (1008 hours)

SurTec 650C

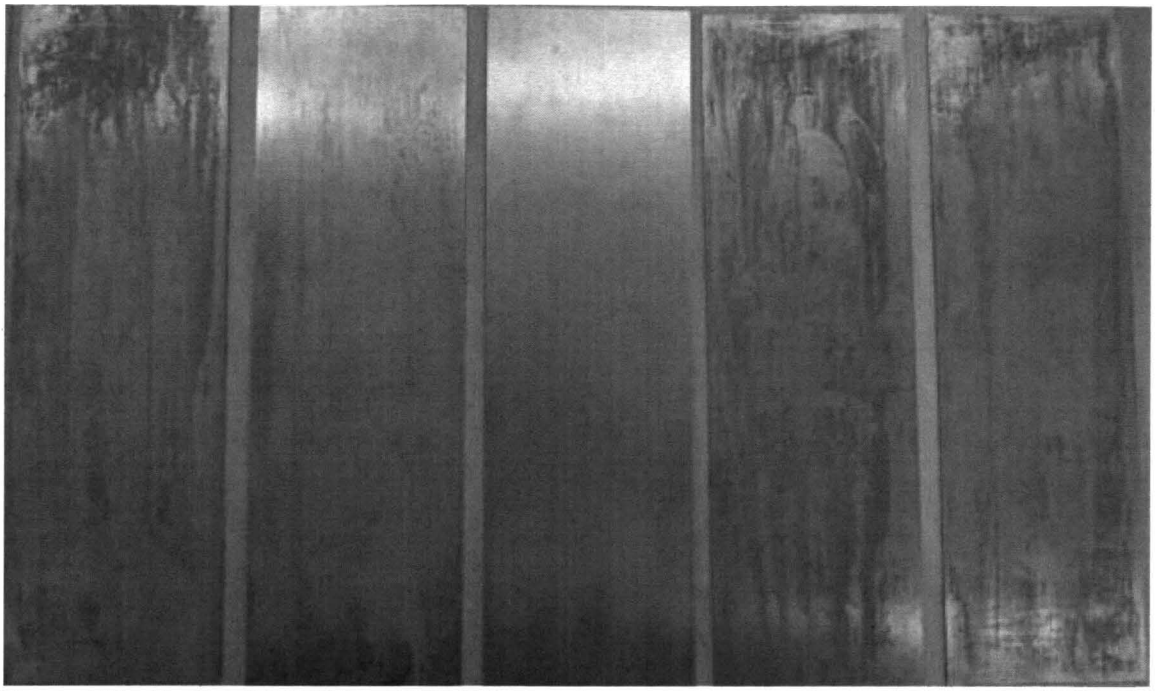

Figure 110 – SurTec 650C, 7011 – 7015 (168 hours)

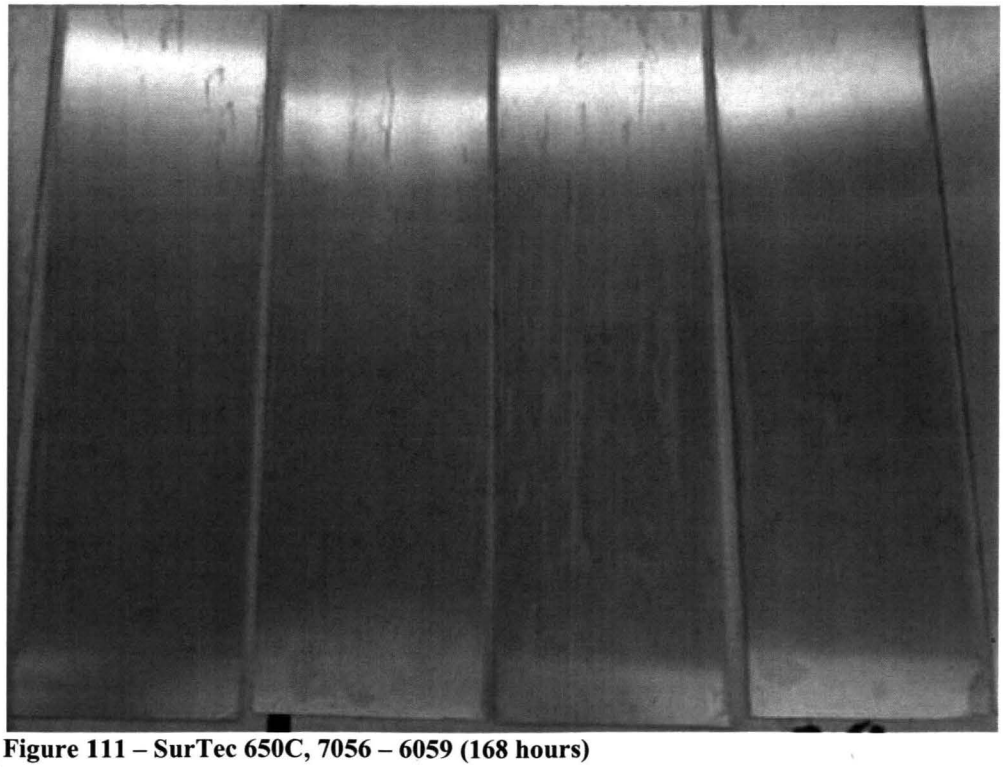

Figure 111 – SurTec 650C, 7056 – 6059 (168 hours)

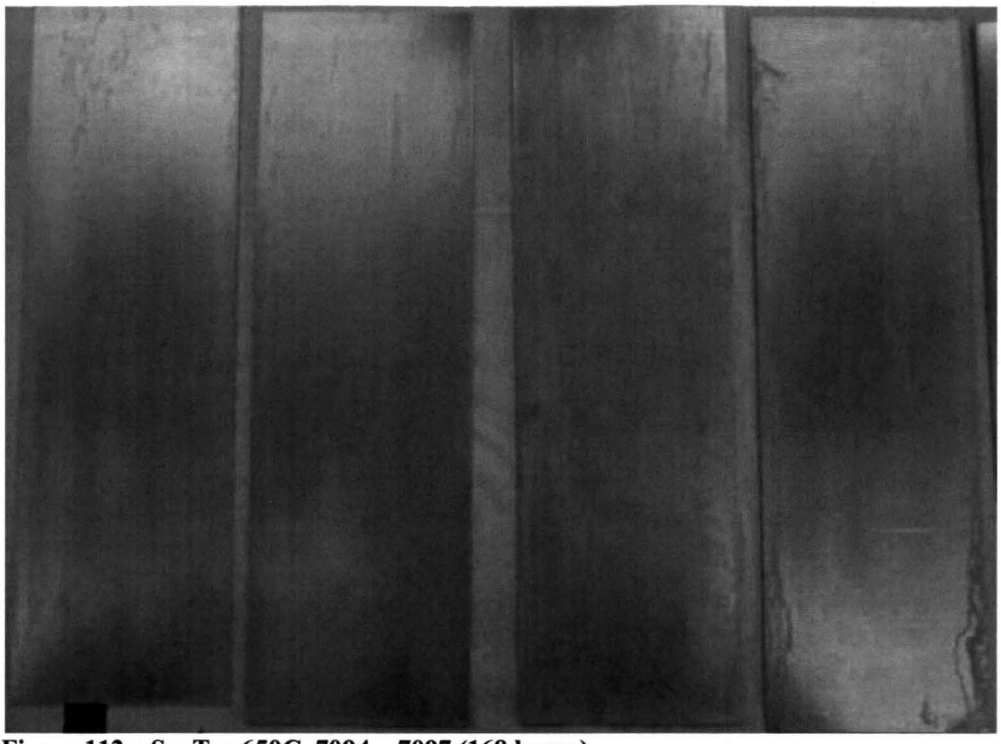

Figure 112 – SurTec 650C, 7094 – 7097 (168 hours)

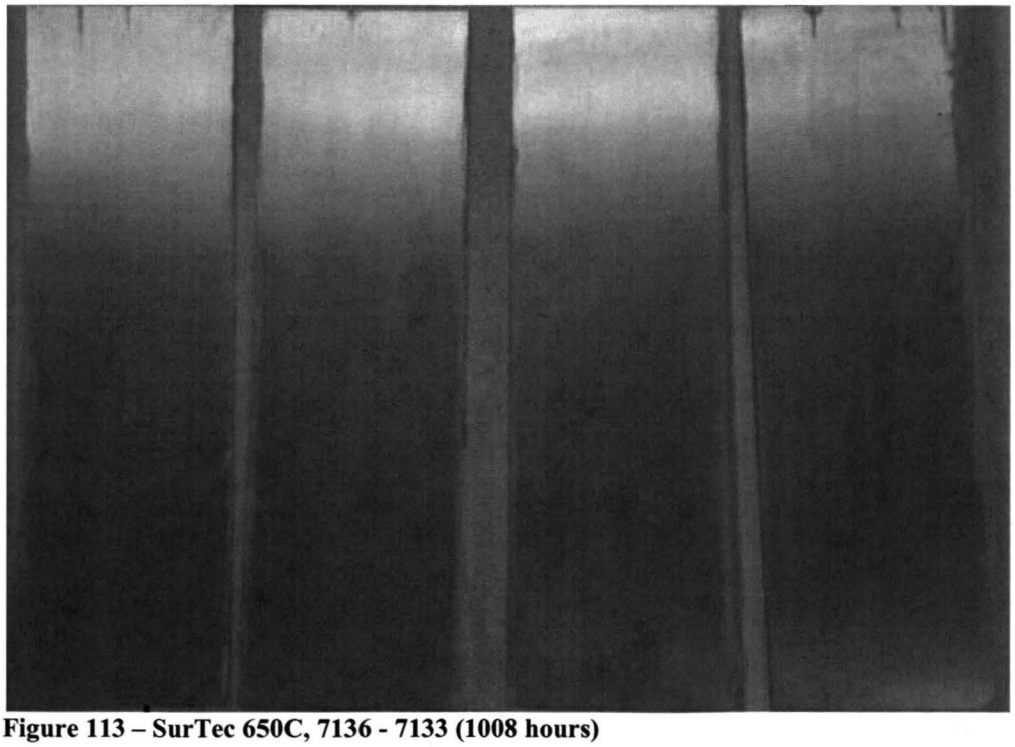

Figure 113 – SurTec 650C, 7136 - 7133 (1008 hours)

Appendix C –
Panel Photographs - ASTM G 85 Annex 5; 168 hours

Alodine 1600

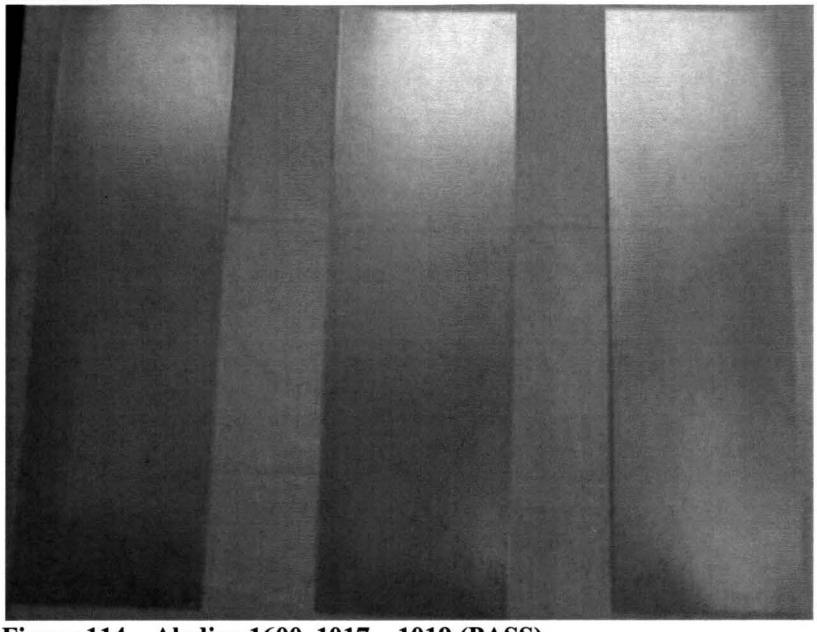

Figure 114 – Alodine 1600, 1017 – 1019 (PASS)

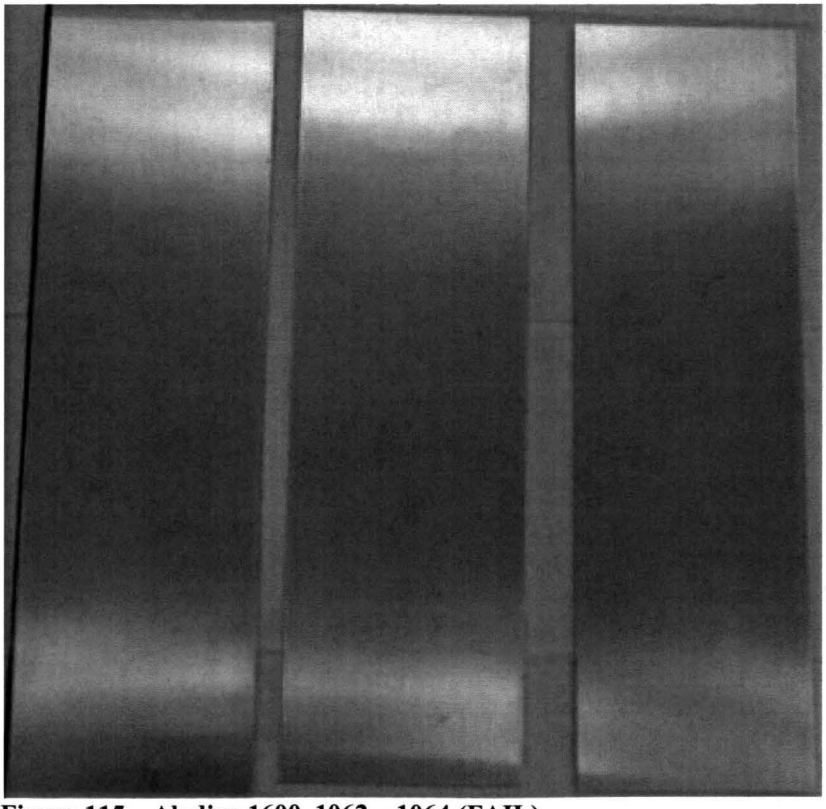

Figure 115 – Alodine 1600, 1062 – 1064 (FAIL)

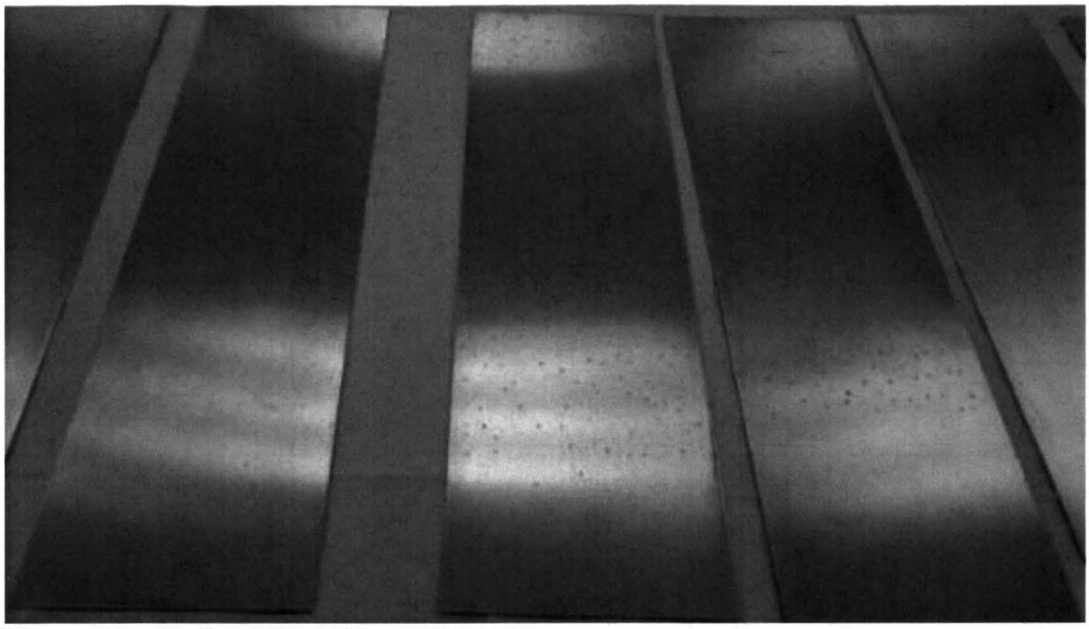

Figure 116 – Alodine 1600, 1100 – 1102 (FAIL)

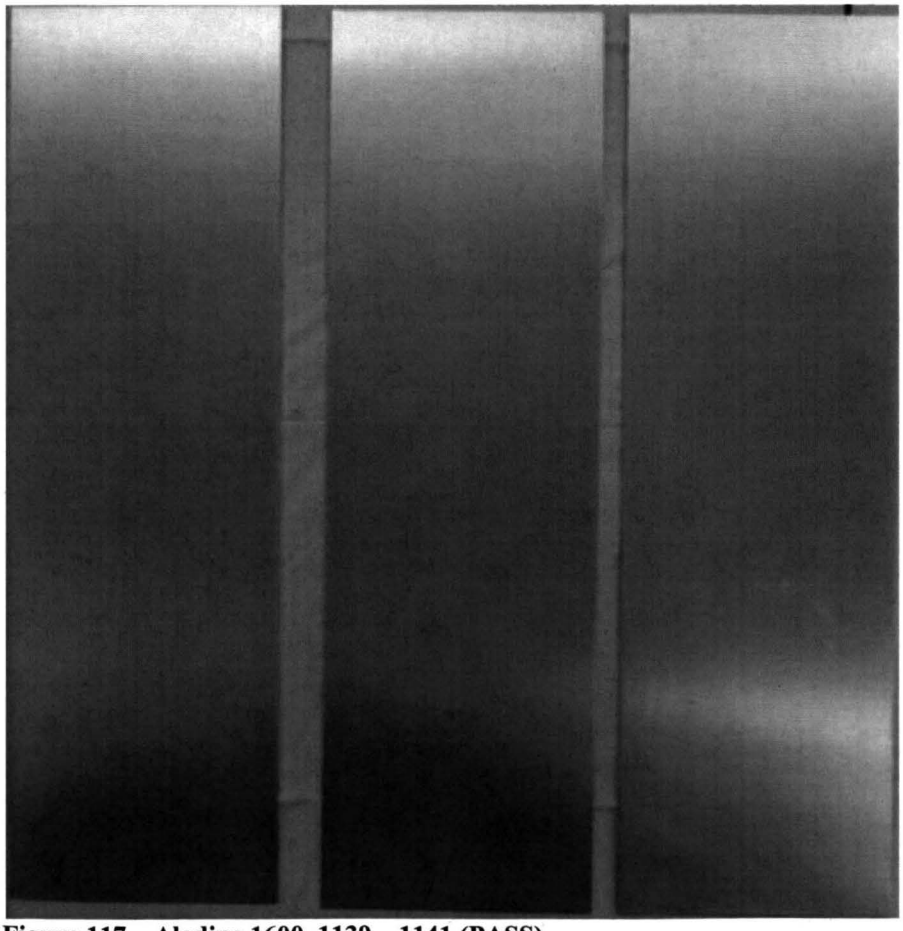

Figure 117 – Alodine 1600, 1139 – 1141 (PASS)

Alodine T 5900 RTU

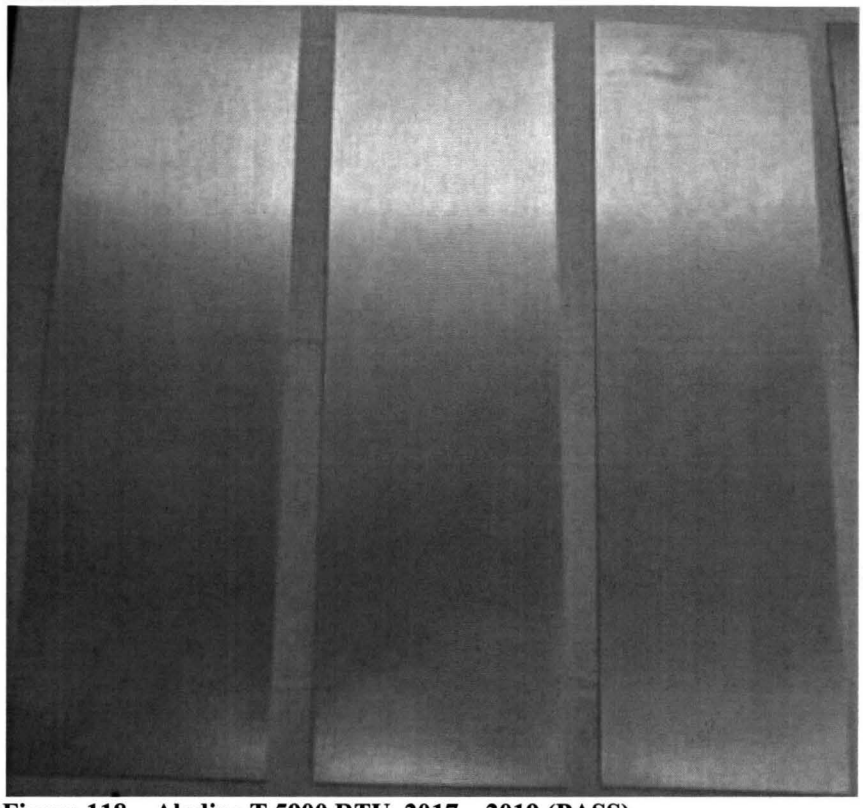

Figure 118 – Alodine T 5900 RTU, 2017 – 2019 (PASS)

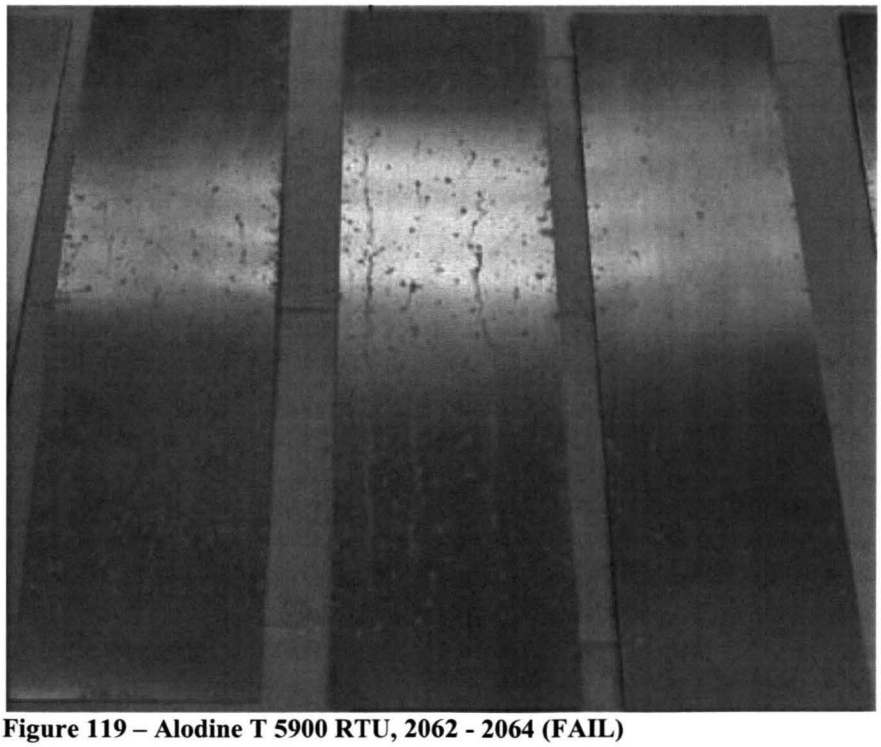

Figure 119 – Alodine T 5900 RTU, 2062 - 2064 (FAIL)

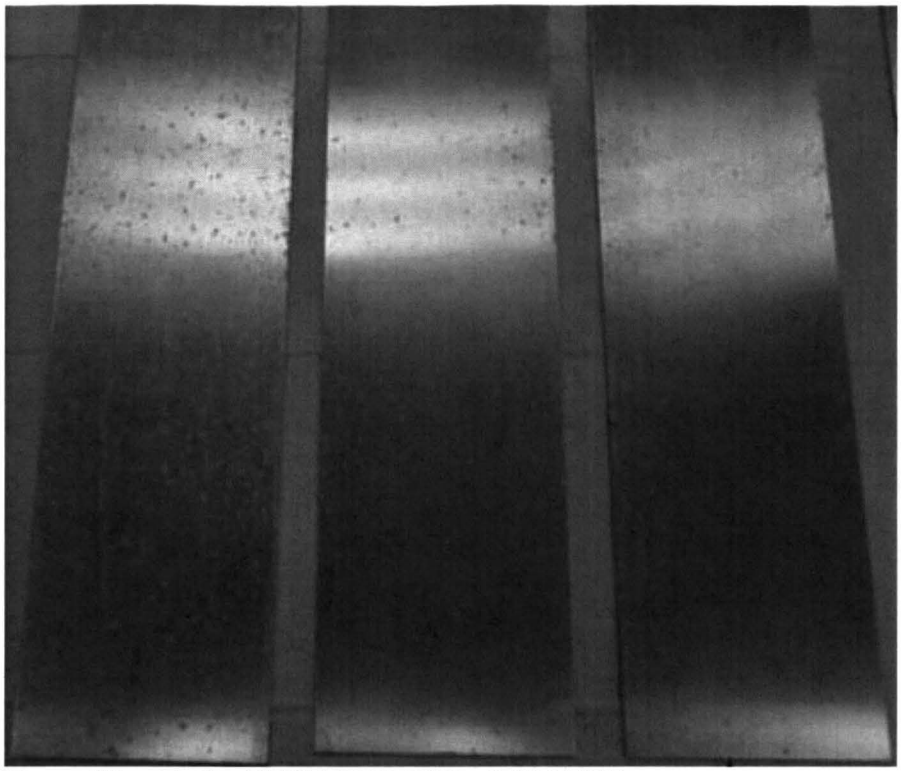

Figure 120 – Alodine T 5900 RTU, 2100 – 2102 (FAIL)

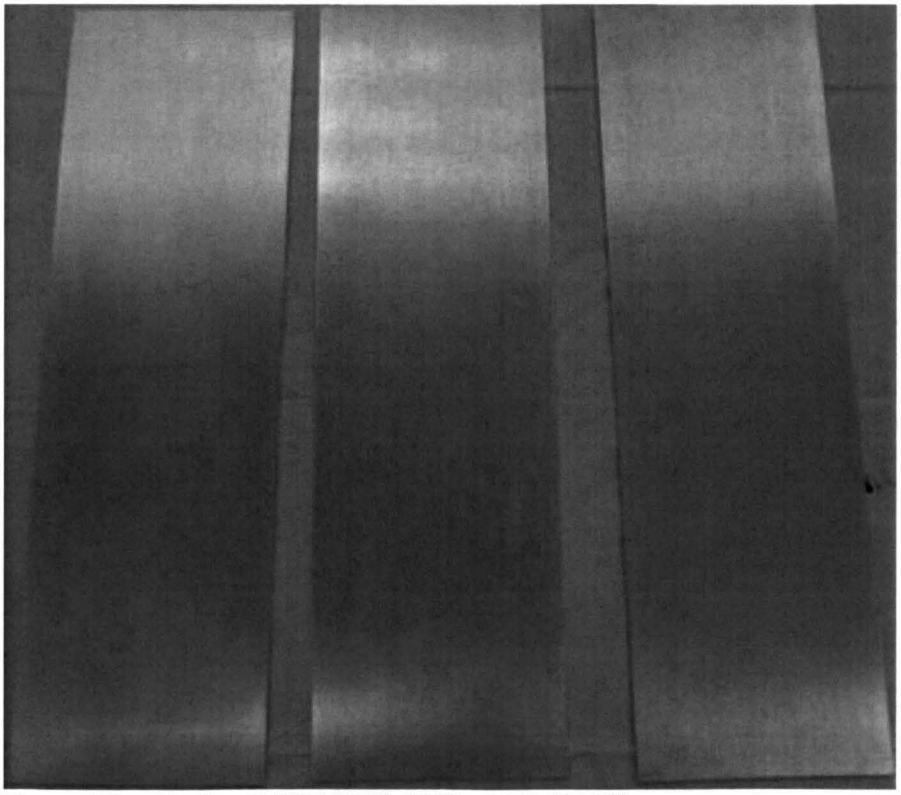

Figure 121 – Alodine T 5900 RTU, 2139 – 2142 (PASS)

Iridite NCP

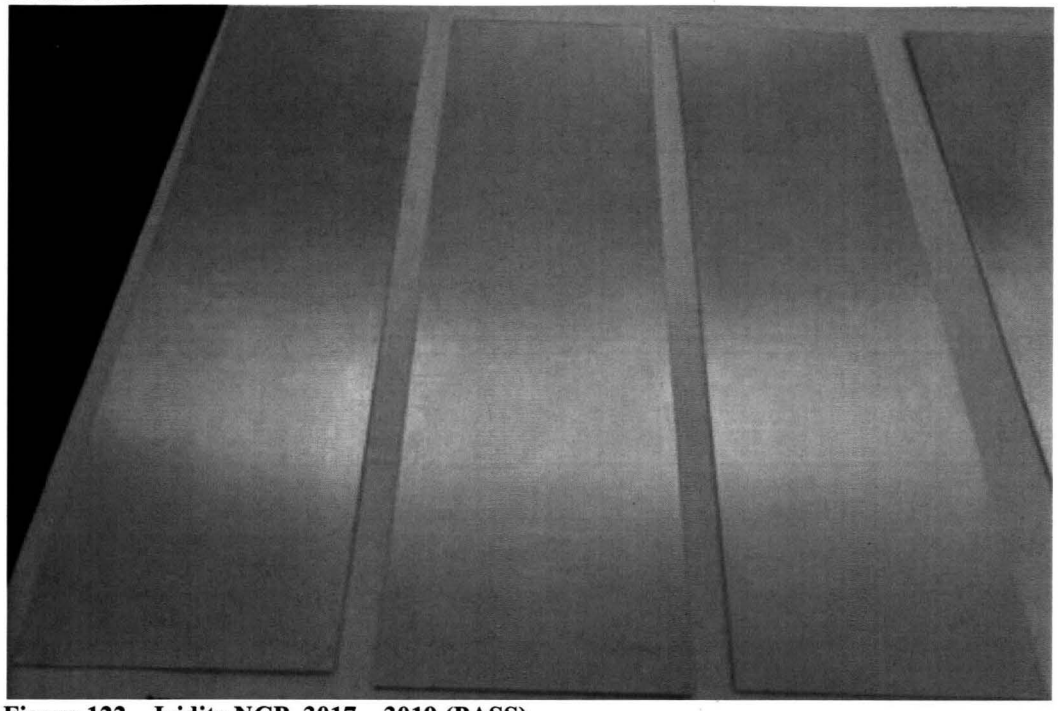

Figure 122 – Iridite NCP, 3017 – 3019 (PASS)

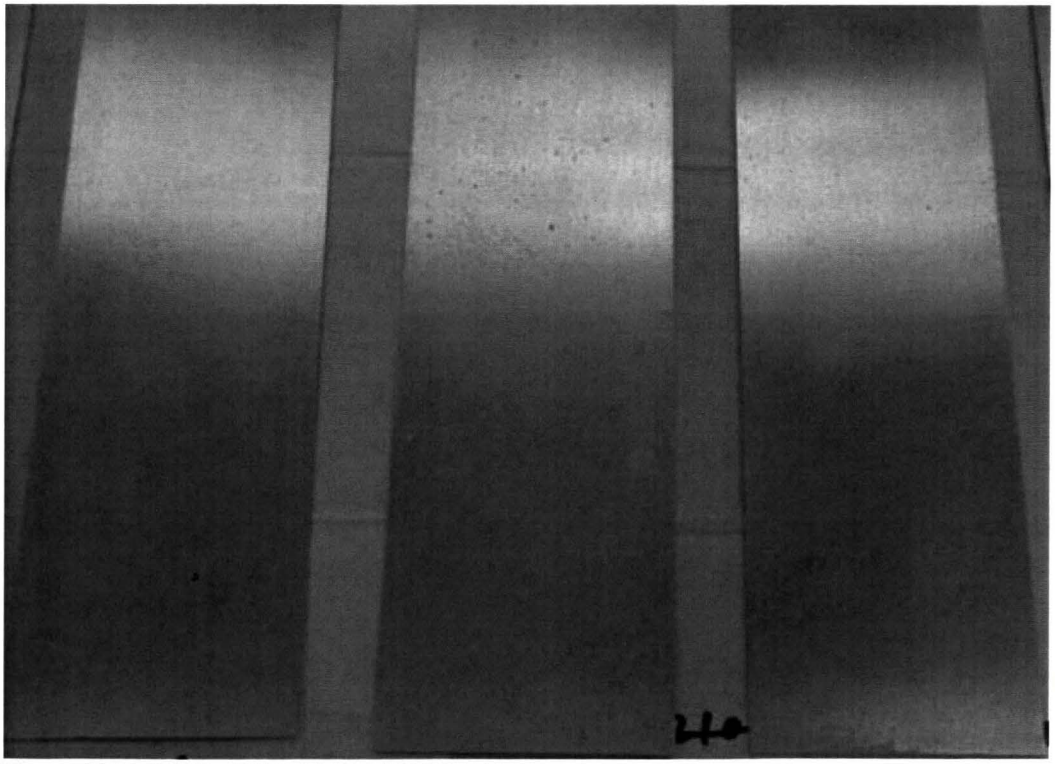

Figure 123 – Iridite NCP, 3062 – 3064 (FAIL)

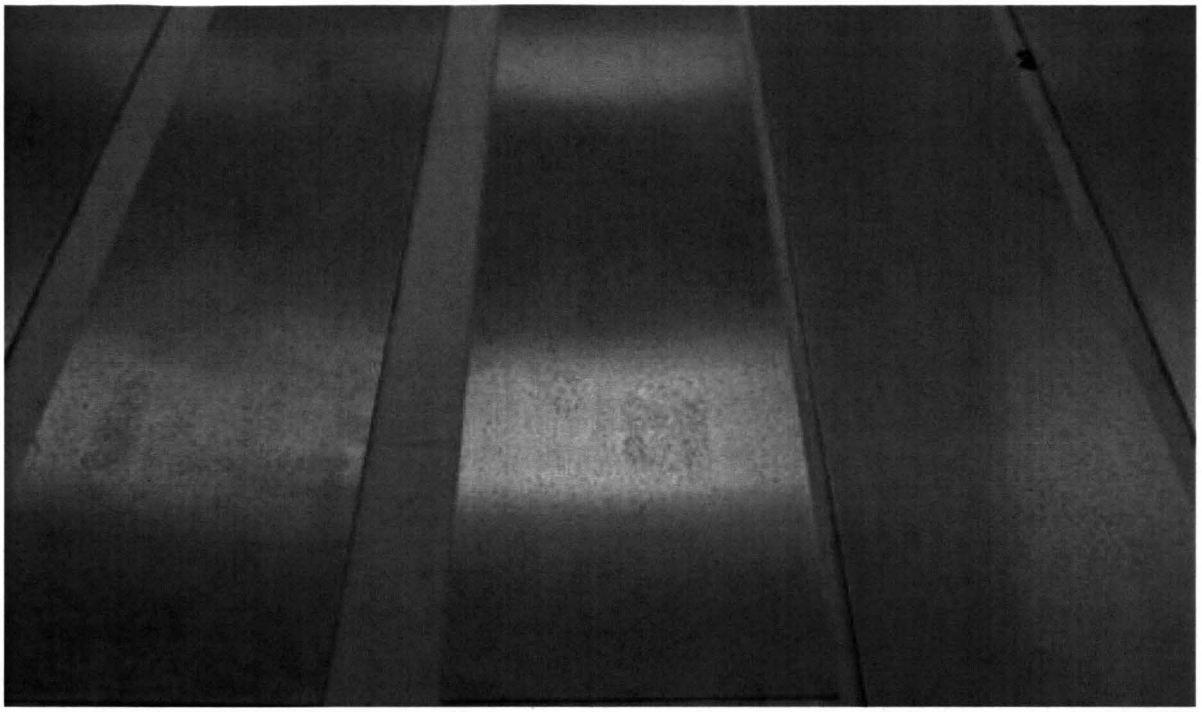

Figure 124 – Iridite NCP, 3100 – 3102 (FAIL)

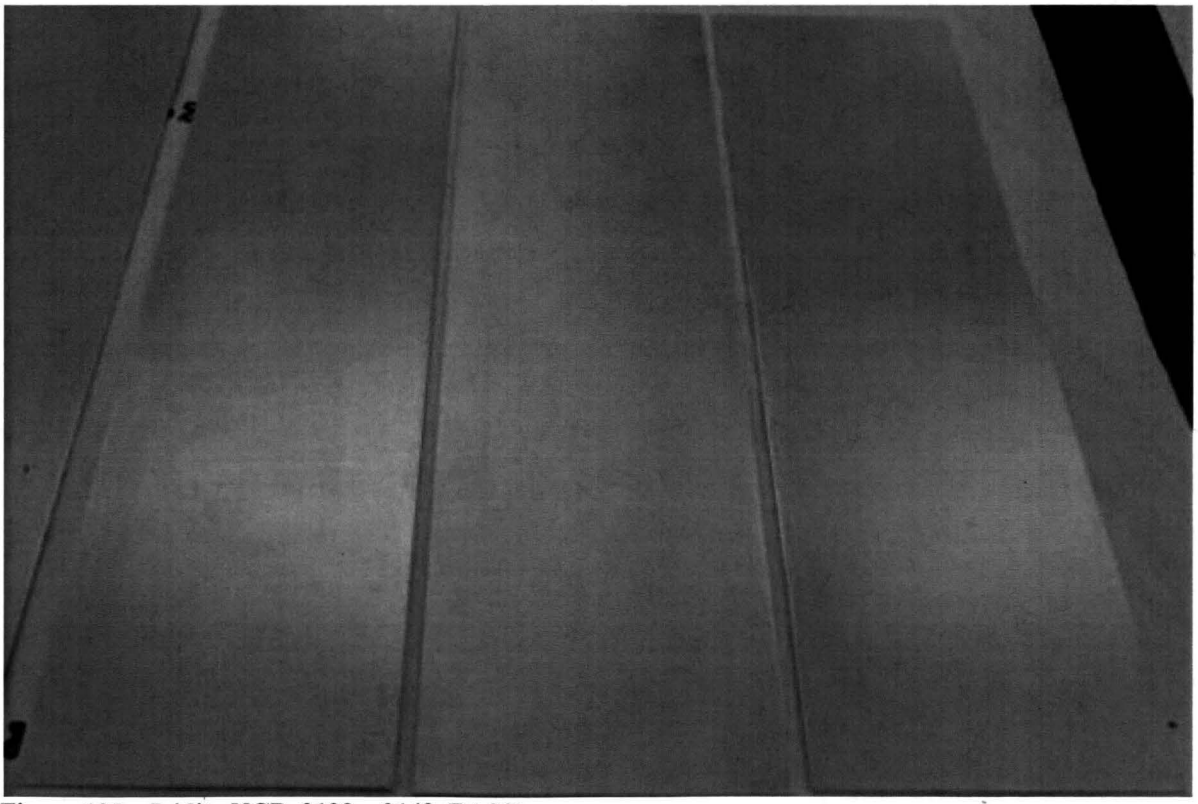

Figure 125 – Iridite NCP, 3139 – 3142 (PASS)

Metalast HF

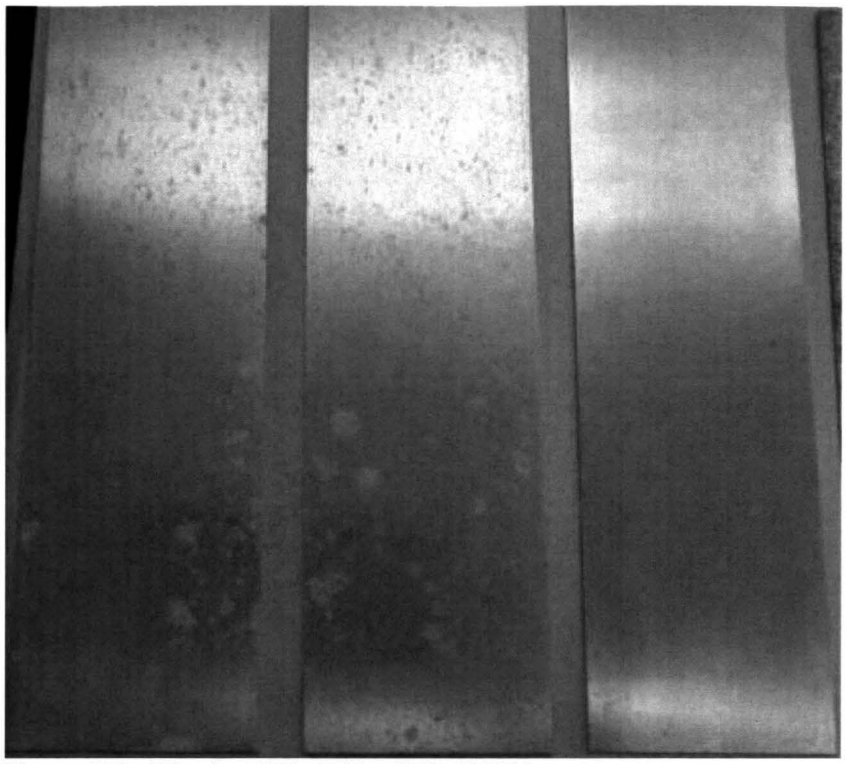

Figure 126 – Metalast HF, 4017 – 4019 (FAIL)

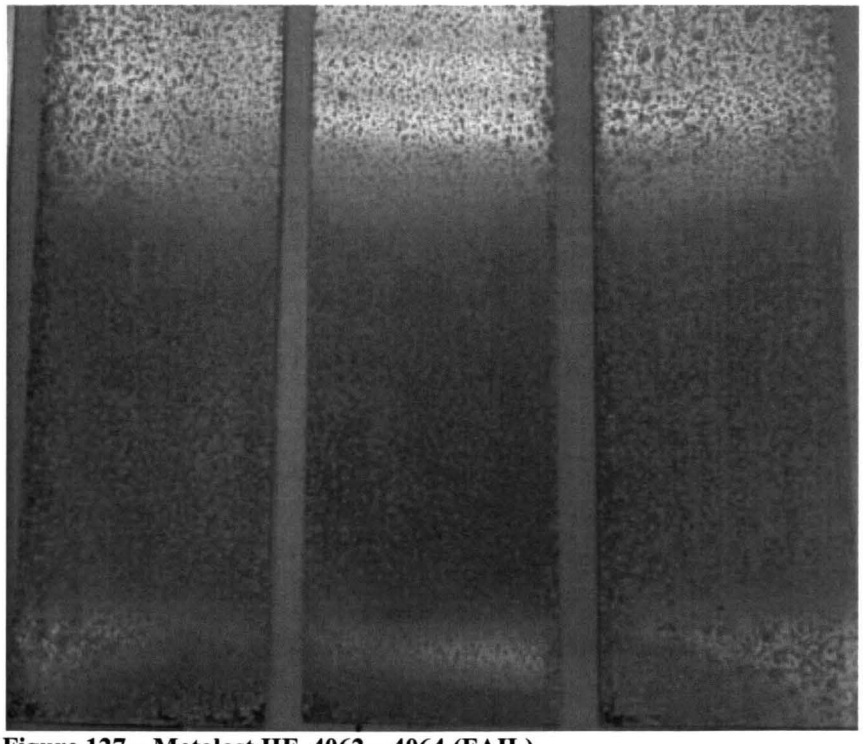

Figure 127 – Metalast HF, 4062 – 4064 (FAIL)

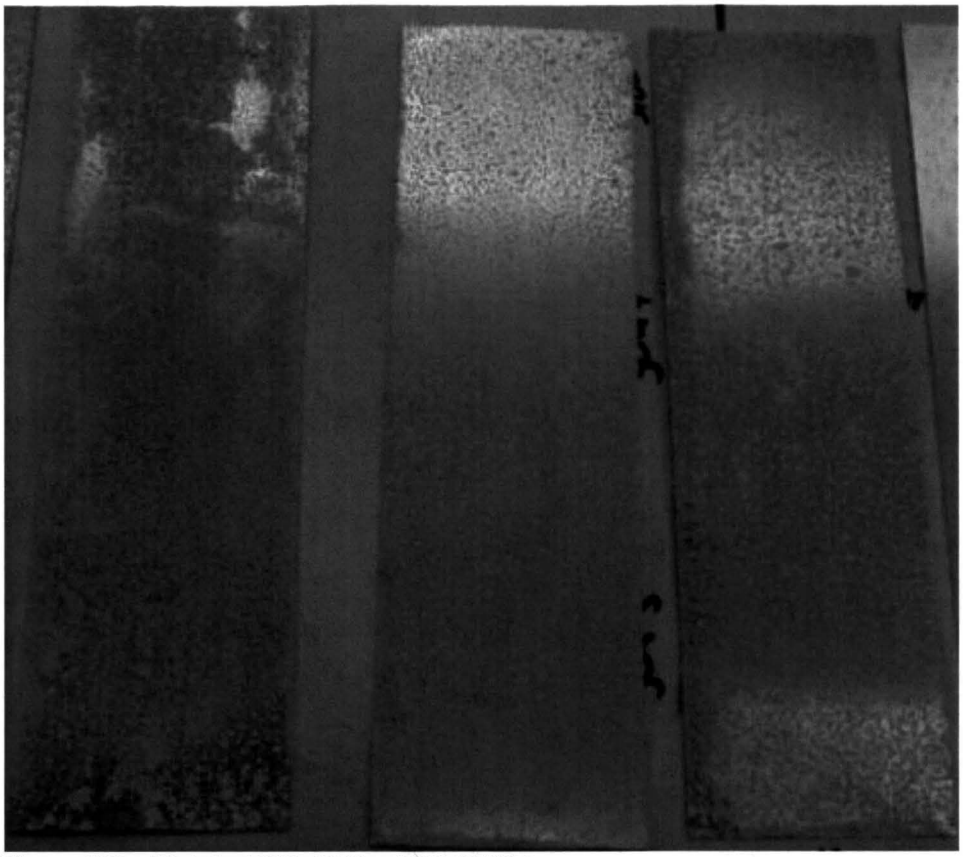

Figure 128 – Metalast HF, 4100 – 4102 (FAIL)

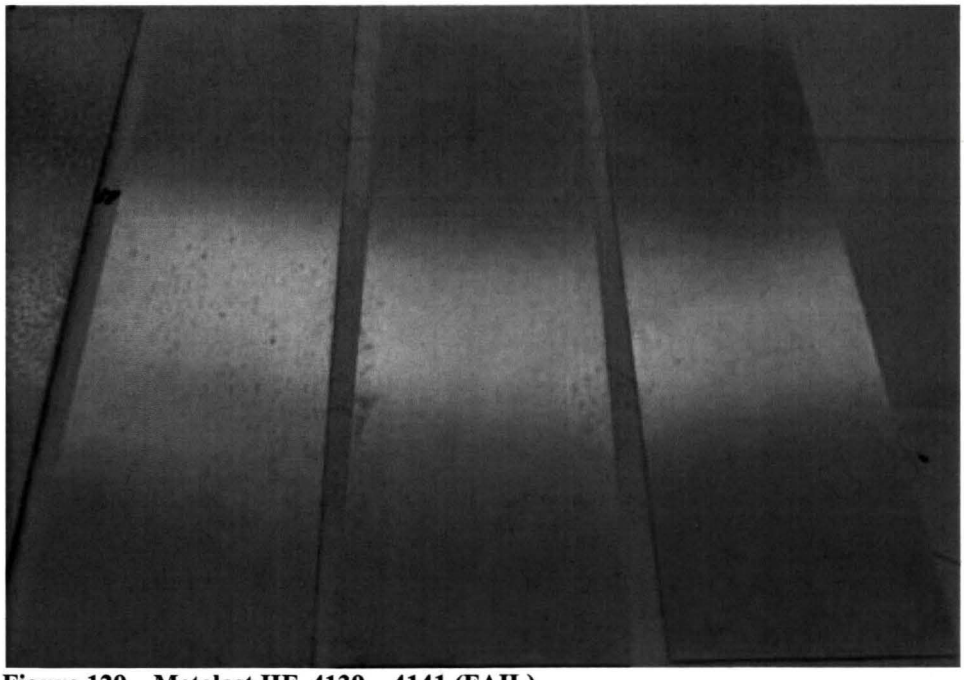

Figure 129 – Metalast HF, 4139 – 4141 (FAIL)

Metalast HF-EPA

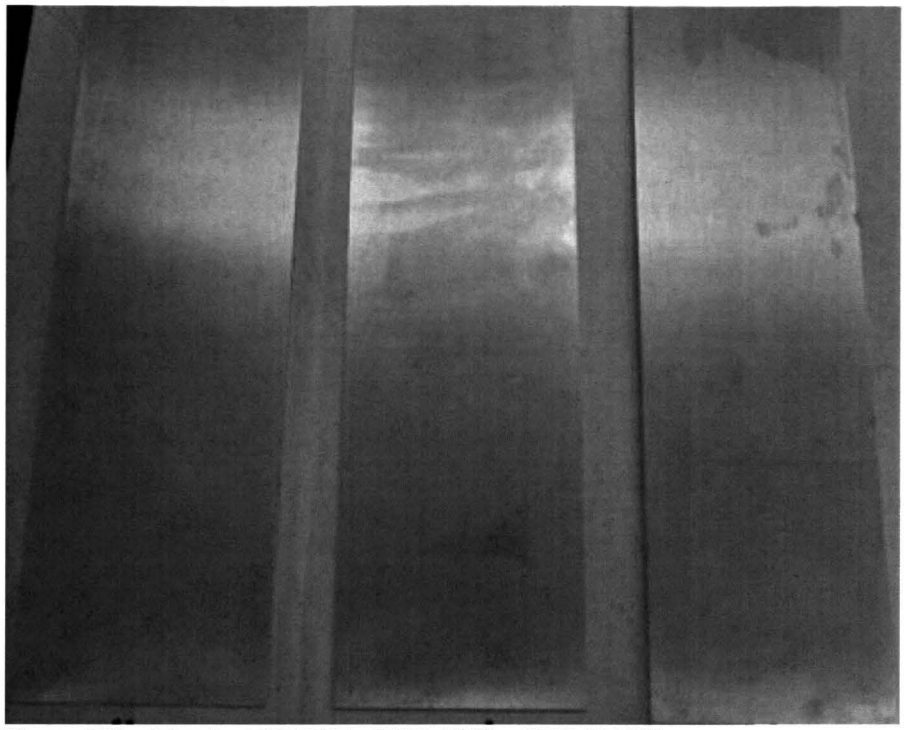

Figure 130 – Metalast HF-EPA, 5016, 5018 – 5019 (PASS)

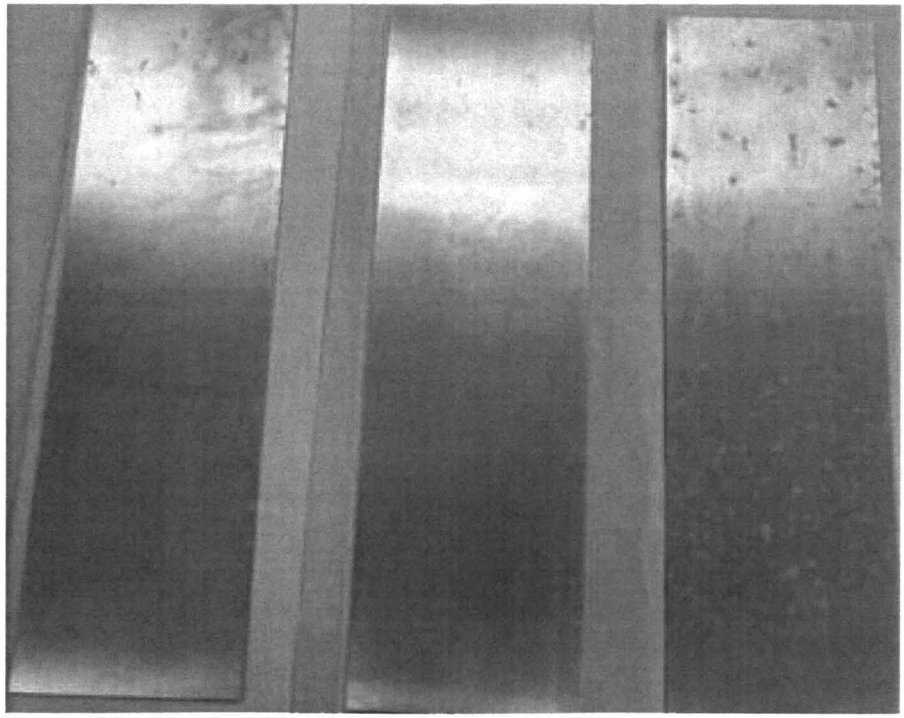

Figure 131 – Metalast HF-EPA, 5062 – 5064 (FAIL)

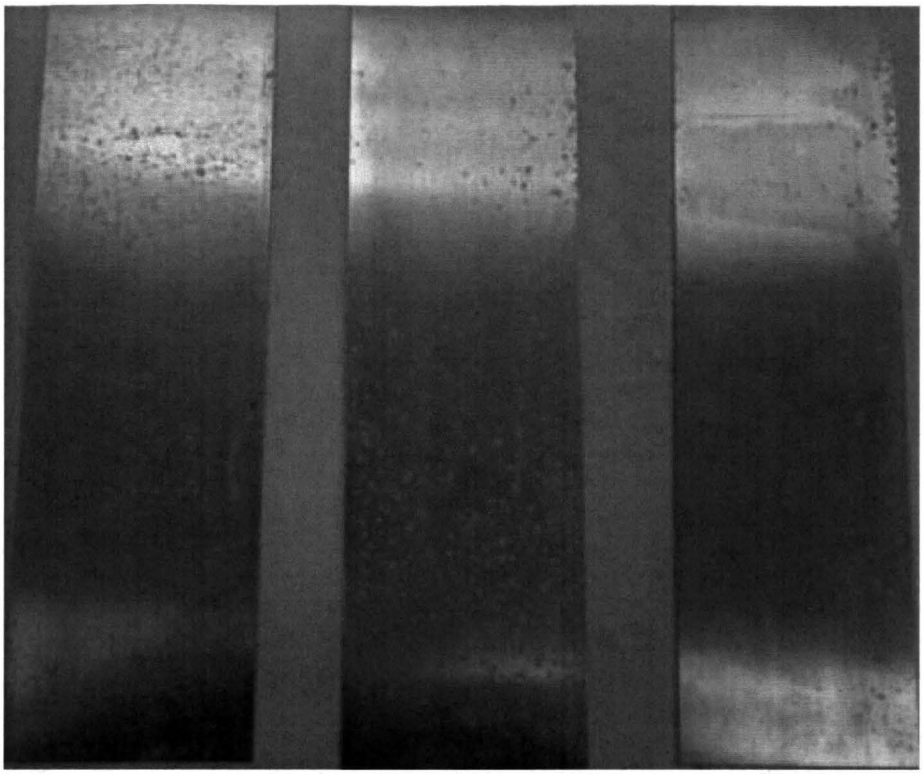

Figure 132 – Metalast HF-EPA, 5100 – 5102 (FAIL)

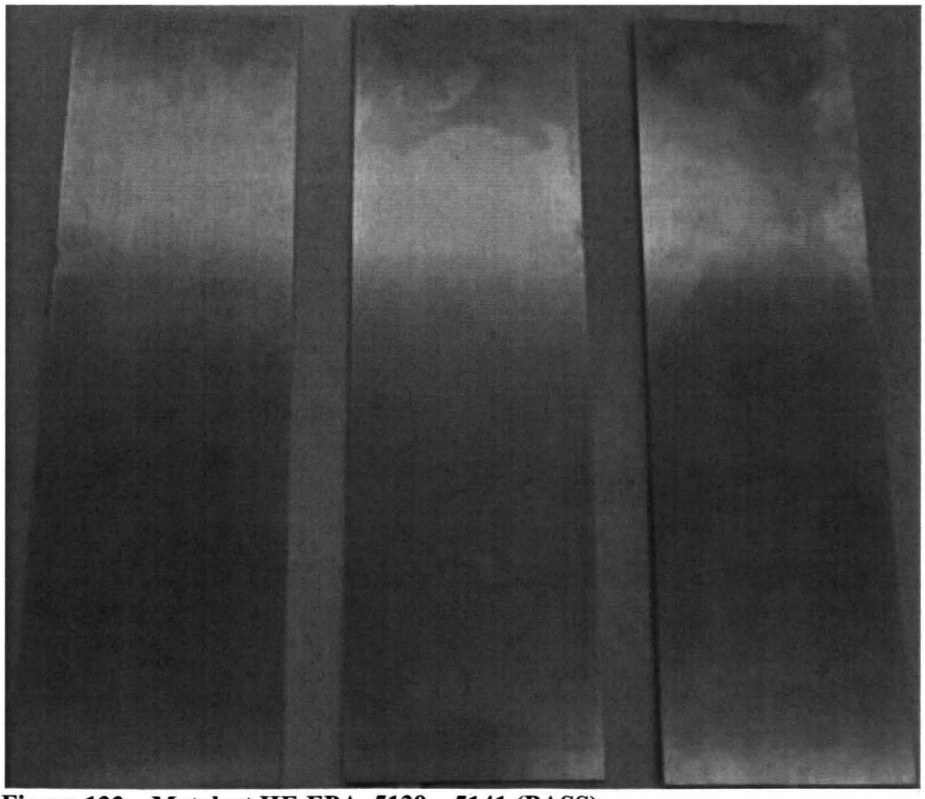

Figure 133 – Metalast HF-EPA, 5139 – 5141 (PASS)

SurTec 650

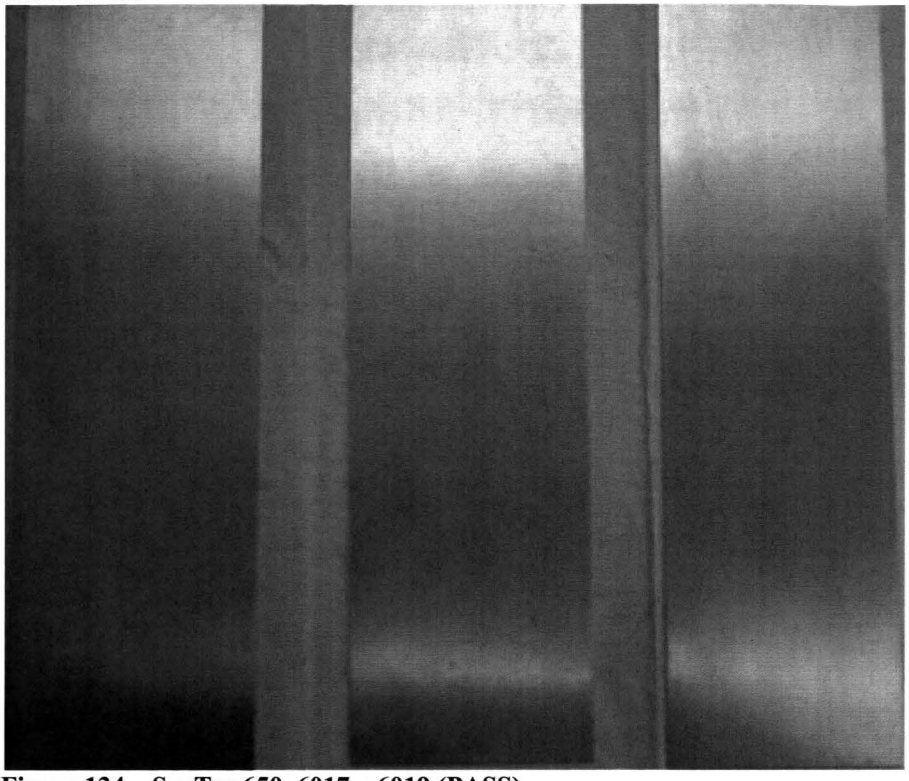

Figure 134 – SurTec 650, 6017 – 6019 (PASS)

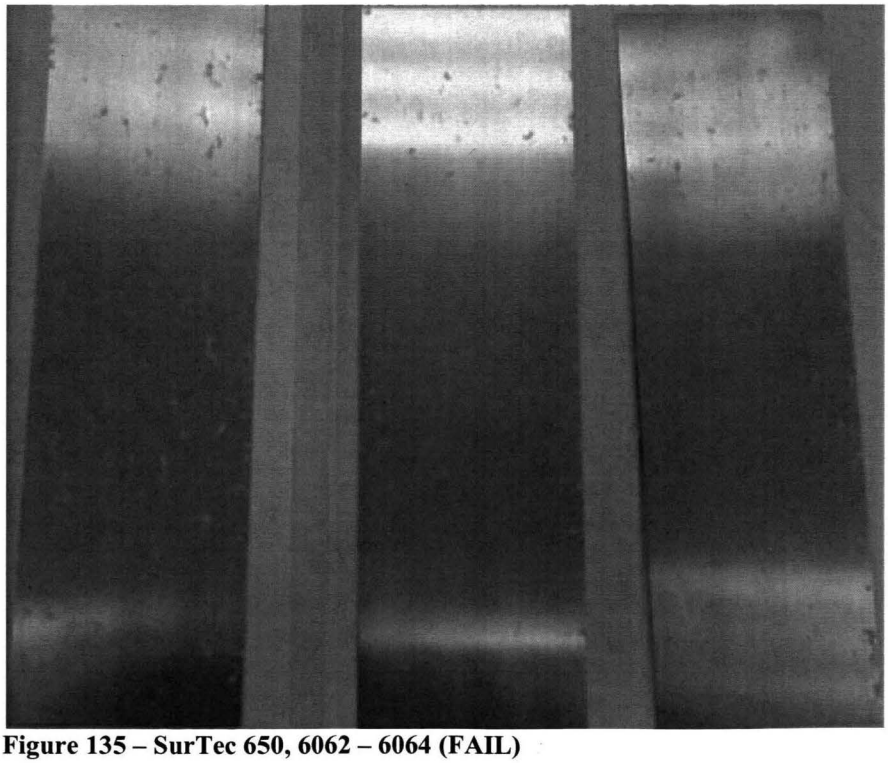

Figure 135 – SurTec 650, 6062 – 6064 (FAIL)

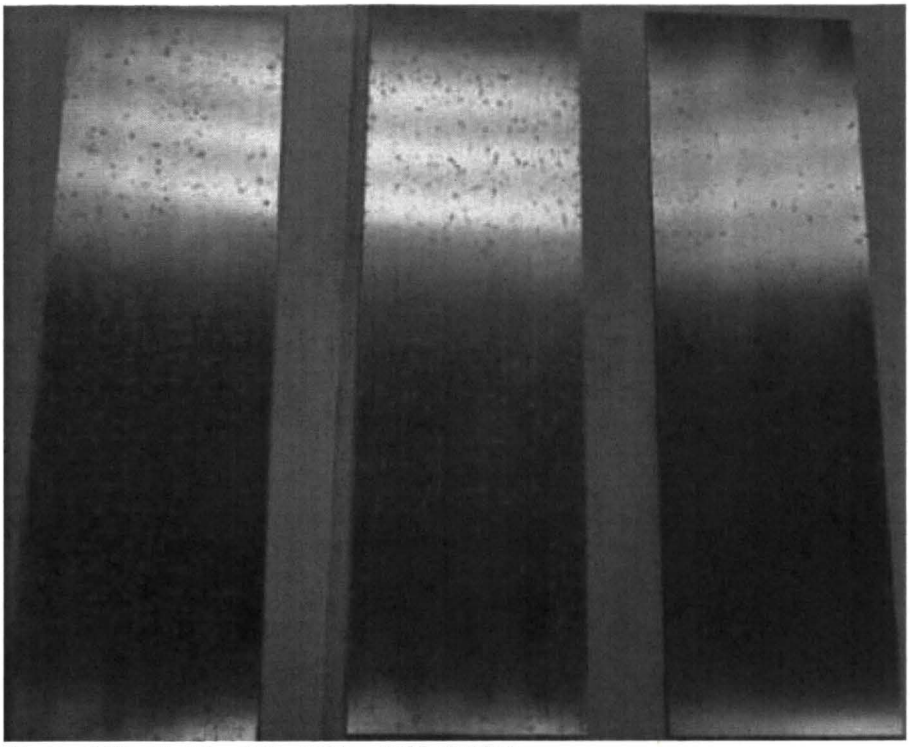

Figure 136 – SurTec 650, 6100 – 6102 (FAIL)

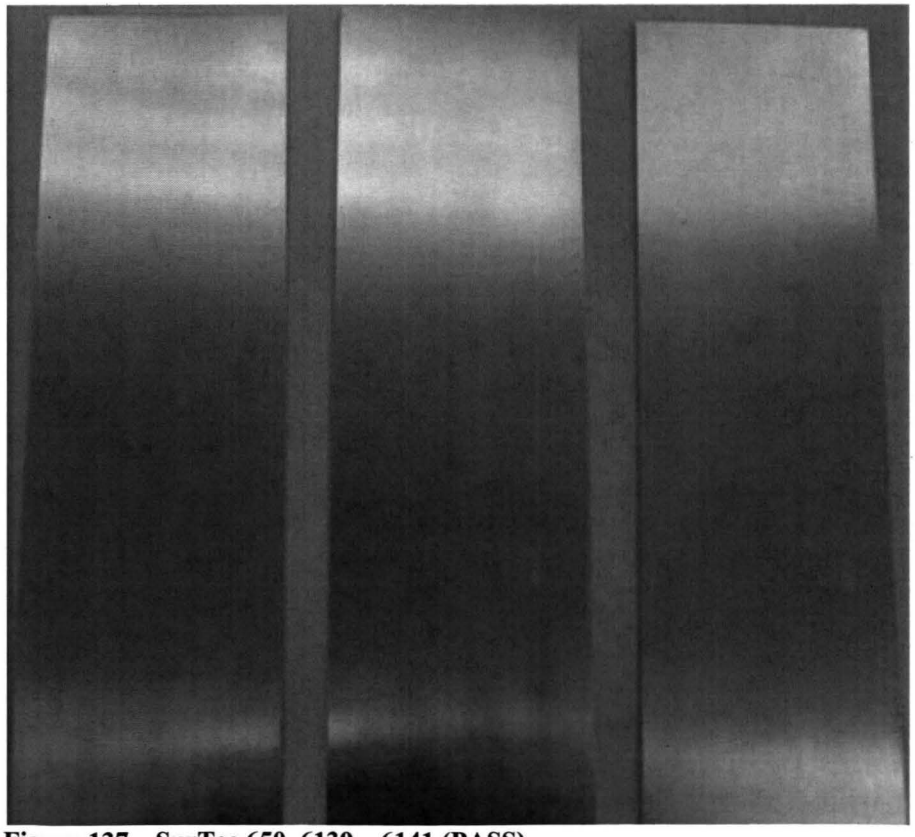

Figure 137 – SurTec 650, 6139 – 6141 (PASS)

SurTec 650C

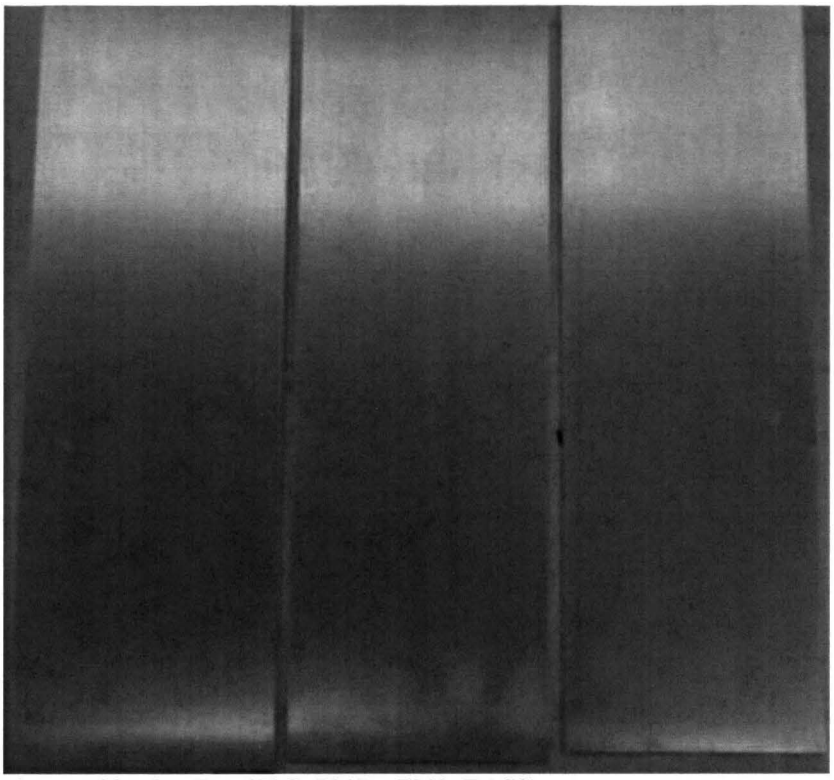

Figure 138 – SurTec 650C, 7017 – 7019 (PASS)

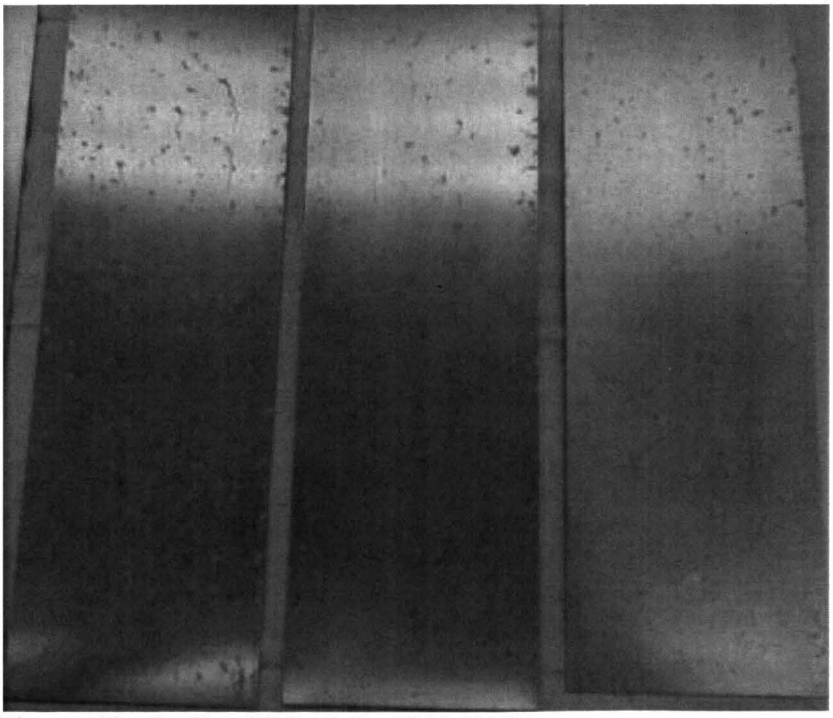

Figure 139 – SurTec 650C, 7062 – 7064 (FAIL)

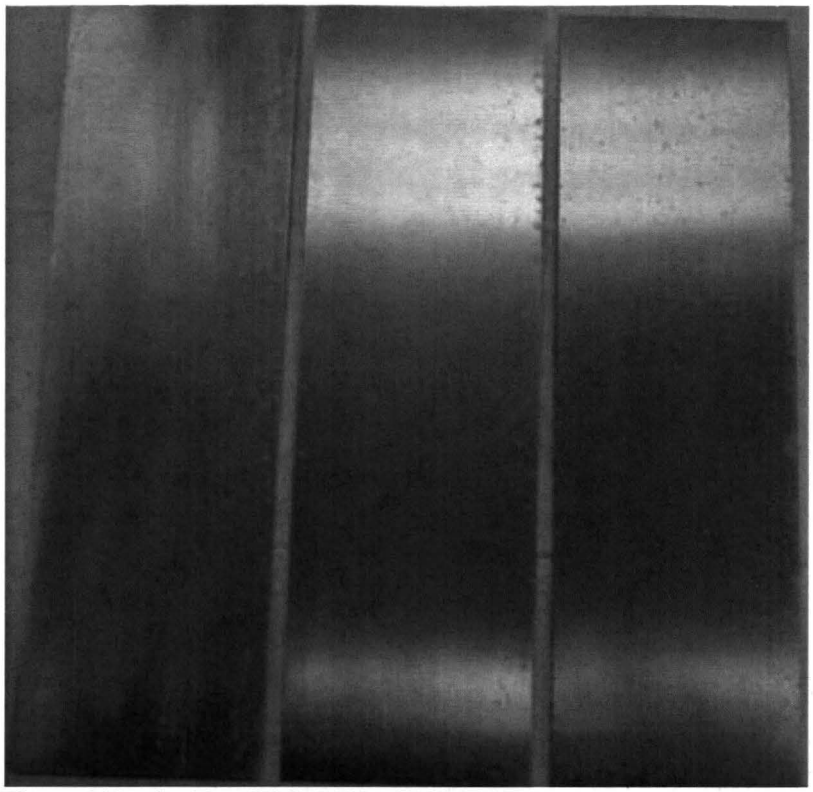

Figure 140 – SurTec 650C, 7100 – 7102 (FAIL)

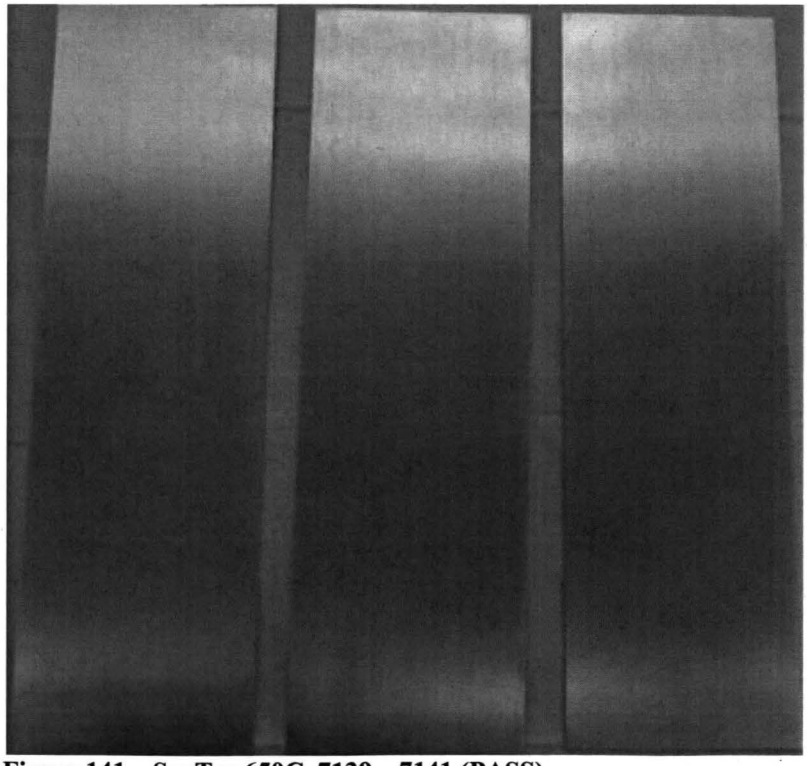

Figure 141 – SurTec 650C, 7139 – 7141 (PASS)

Appendix D –
Rack Photographs – Beach Exposure; Day 1

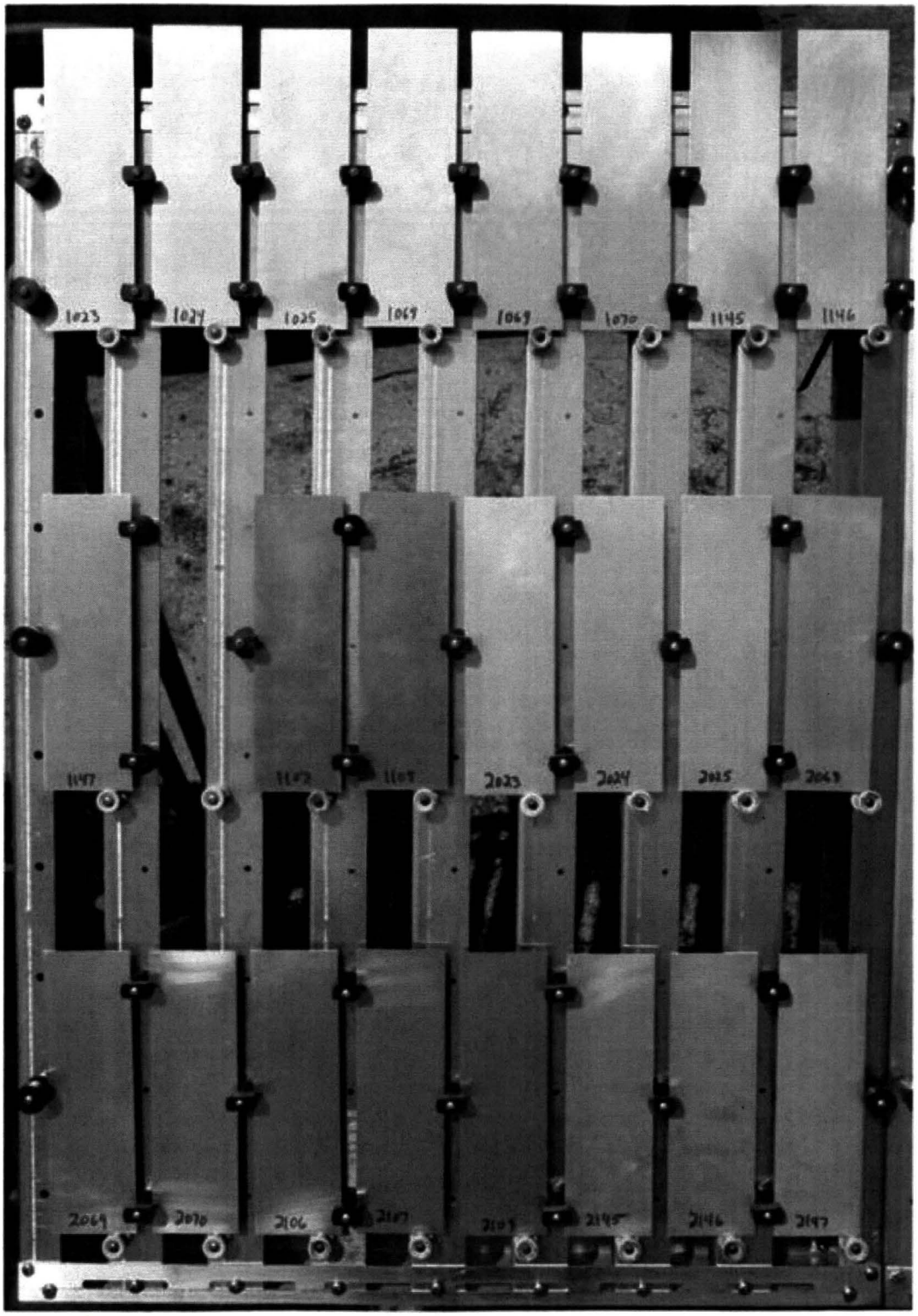

Figure 142 - Beachside Corrosion; Rack 1

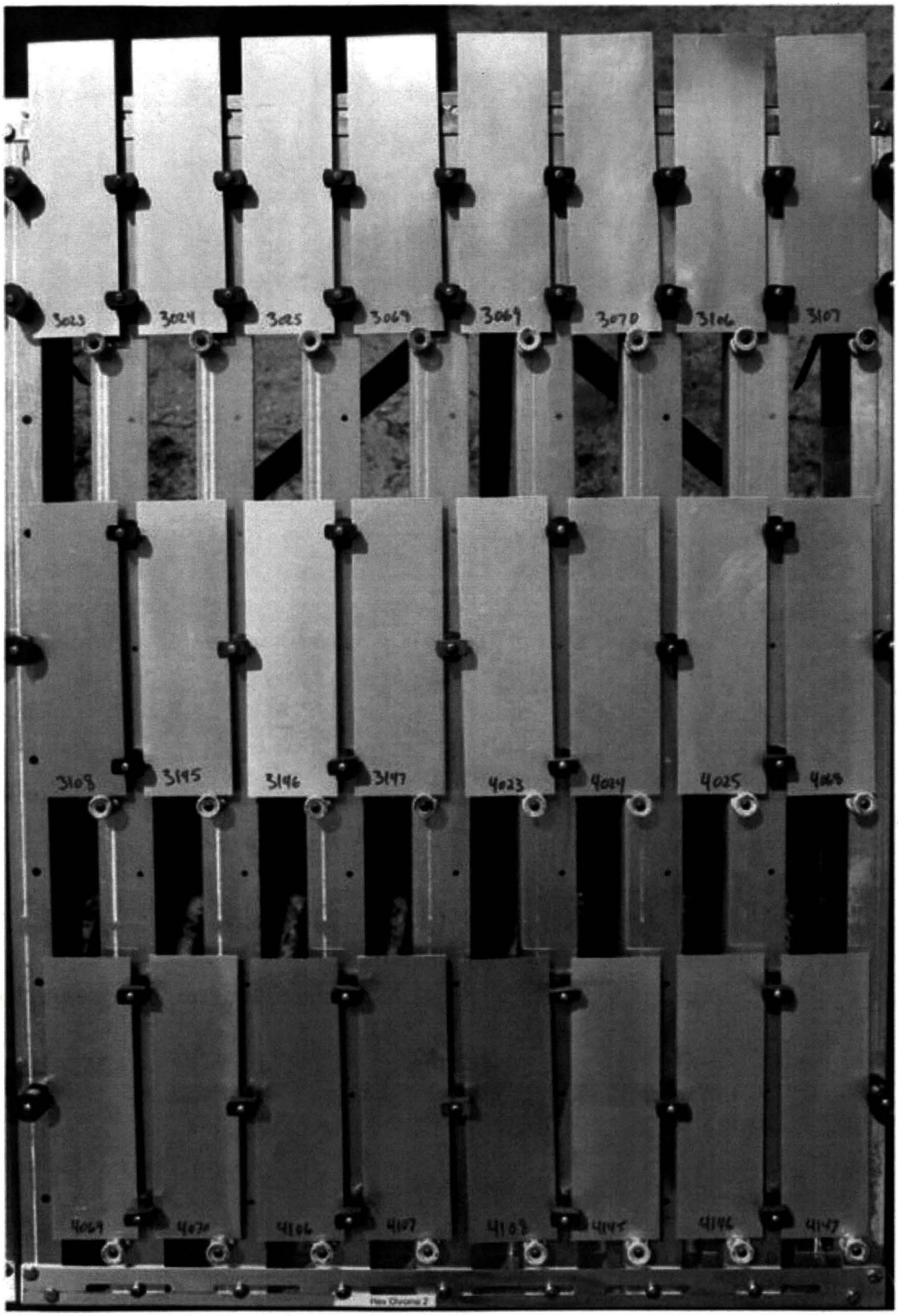

Figure 143 - Beachside Corrosion; Rack 2

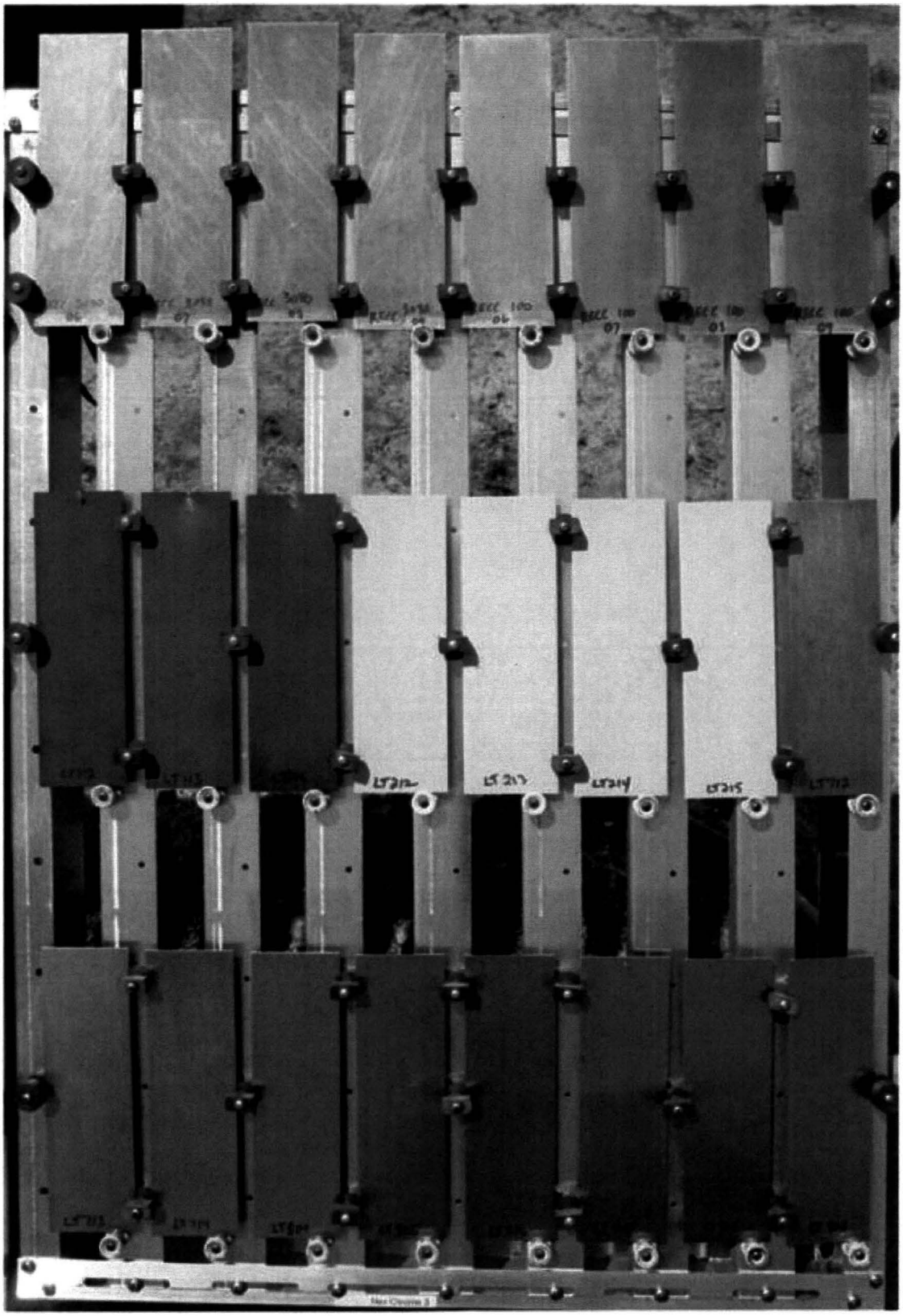

Figure 144 - Beachside Corrosion; Rack 3

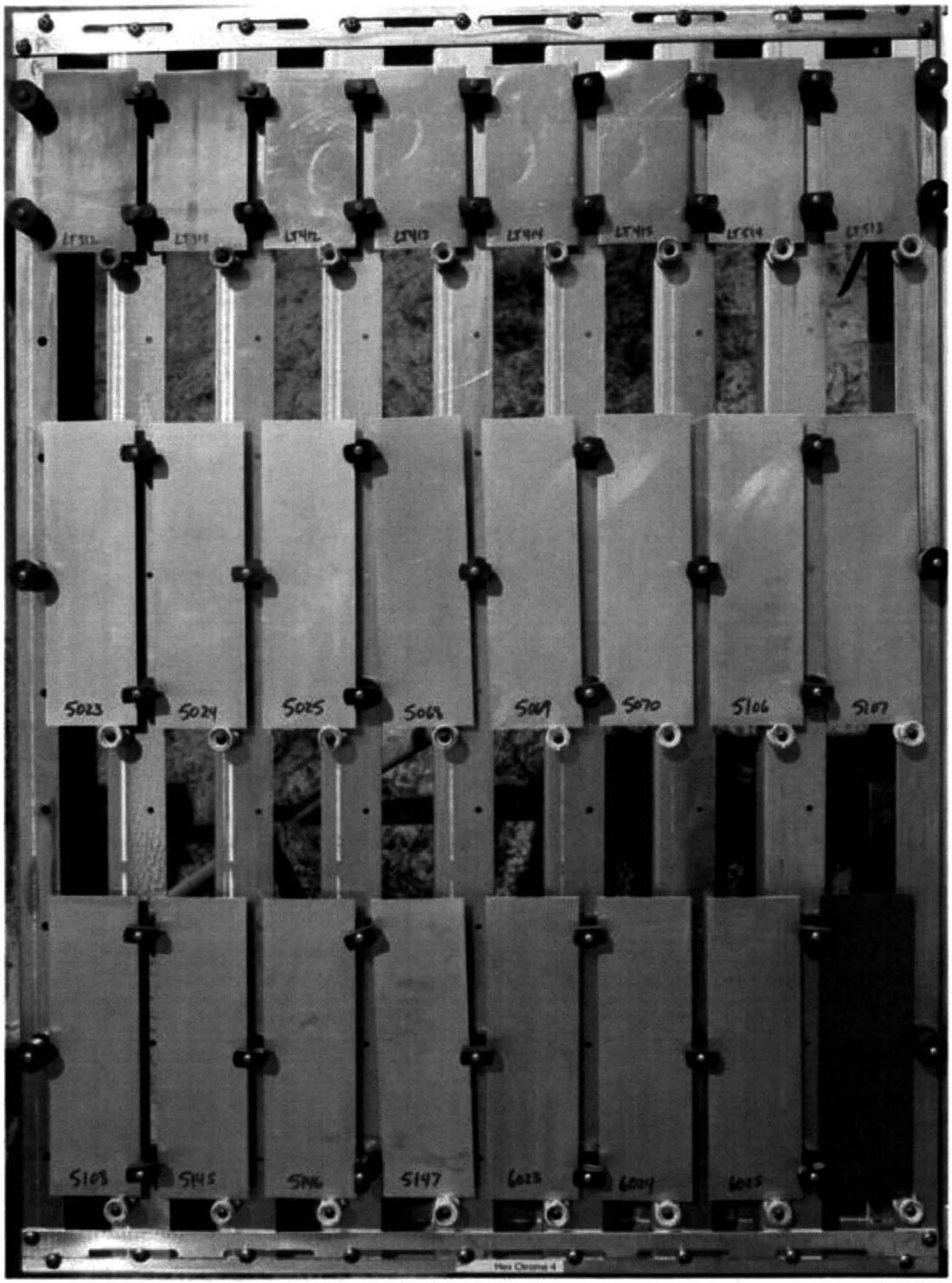

Figure 145 - Beachside Corrosion; Rack 4

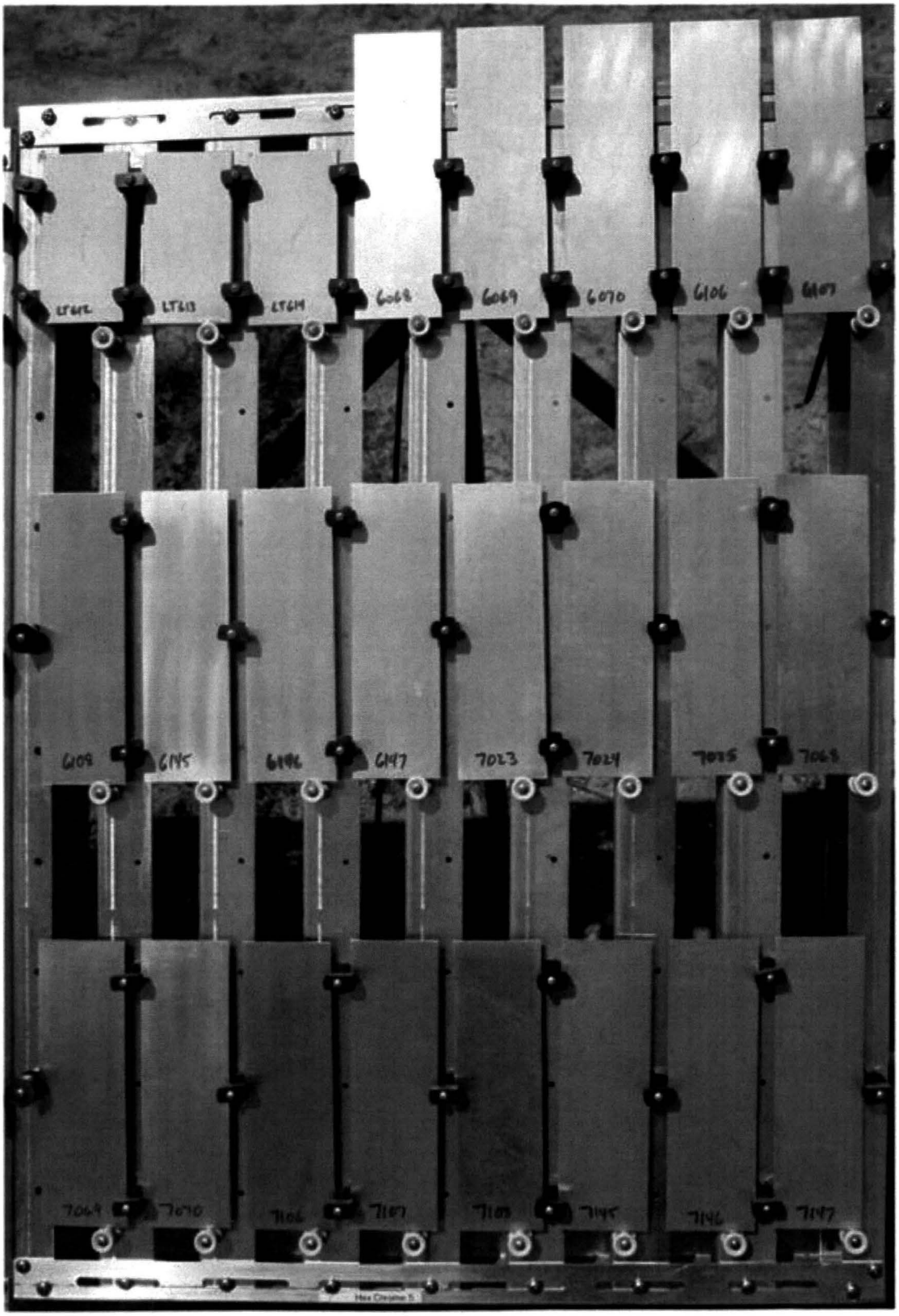

Figure 146 - Beachside Corrosion; Rack 5

Appendix E –
Panel Photographs - Beach Exposure; 5 Weeks

Alodine 1600

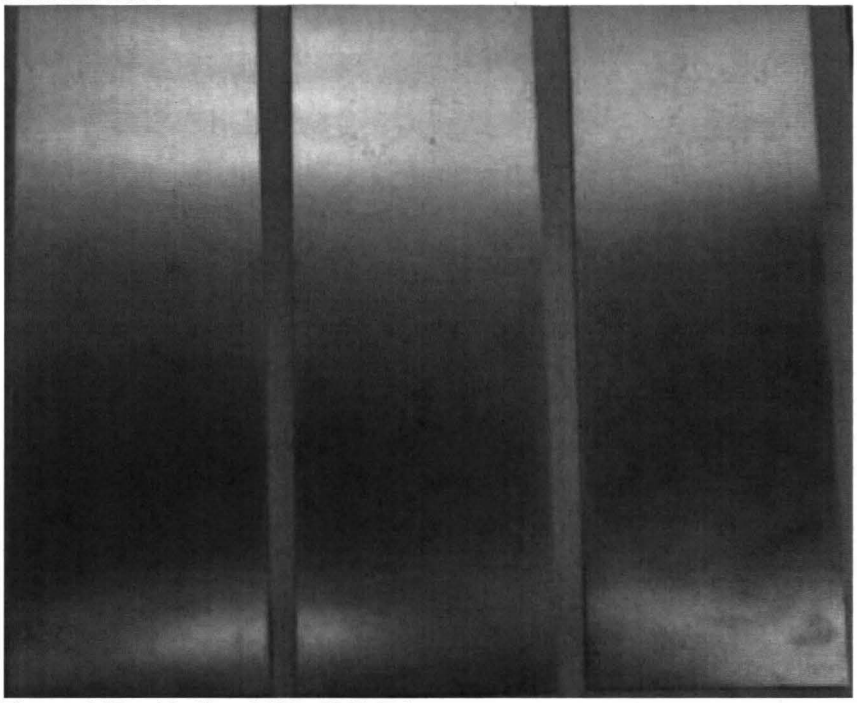

Figure 147 – Alodine 1600, 6061-T6

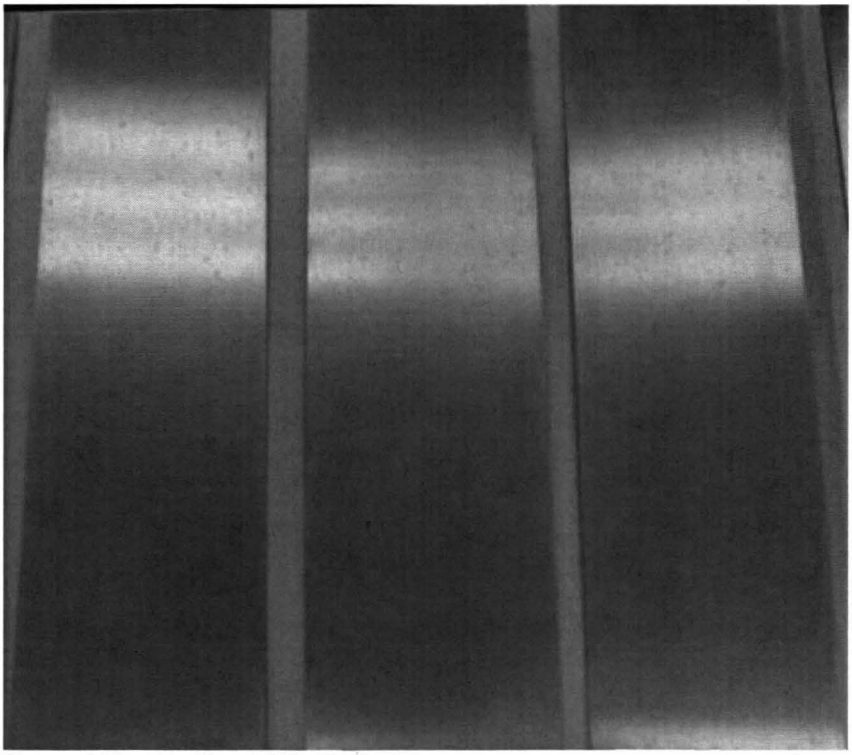

Figure 148 – Alodine 1600, 7075-T73

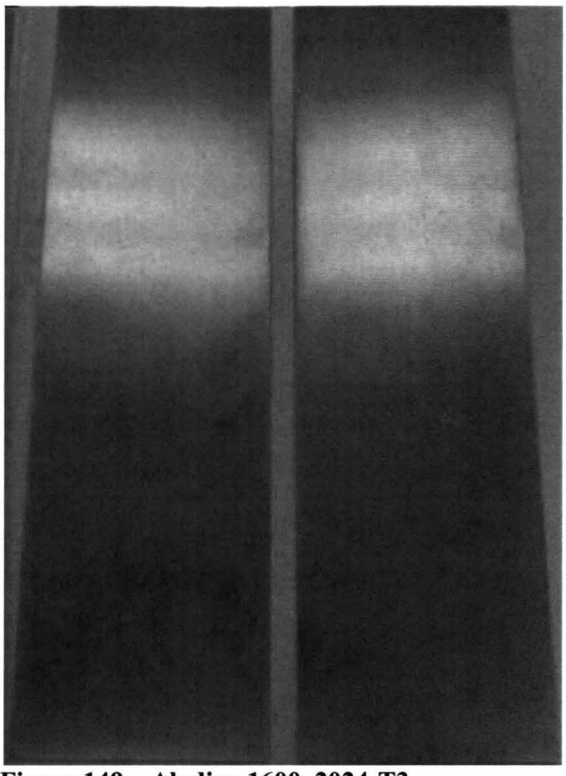

Figure 149 – Alodine 1600, 2024-T3

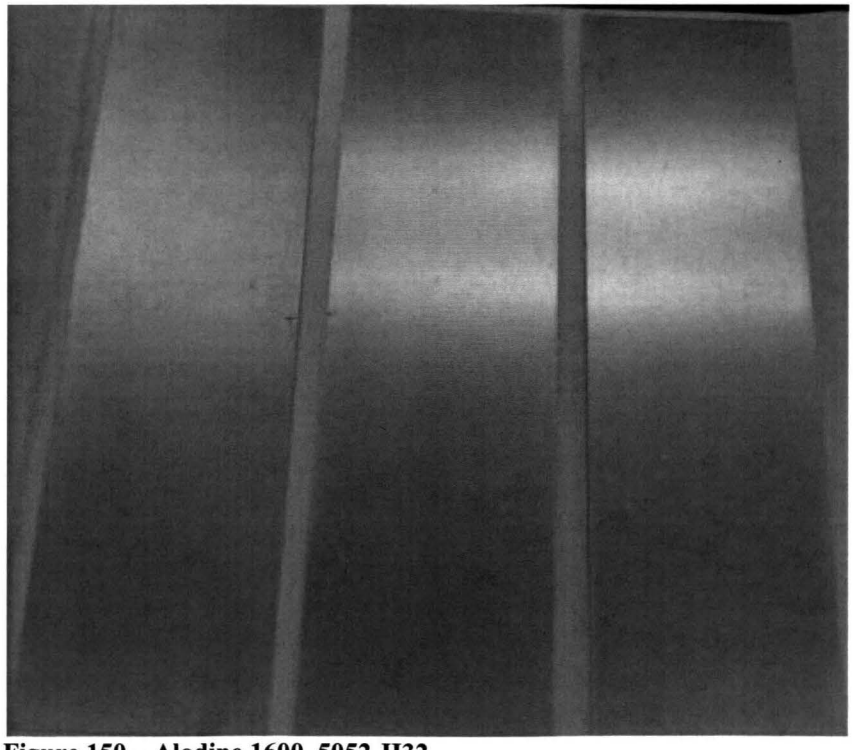

Figure 150 – Alodine 1600, 5052-H32

Alodine T 5900 RTU

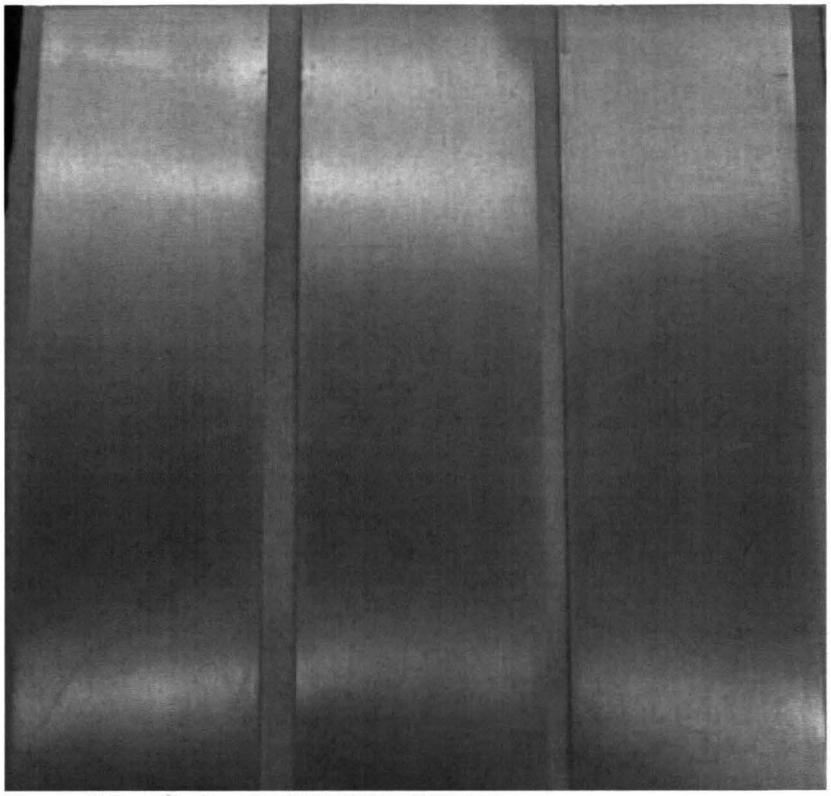

Figure 151 – Alodine T 5900 RTU, 6061-T6

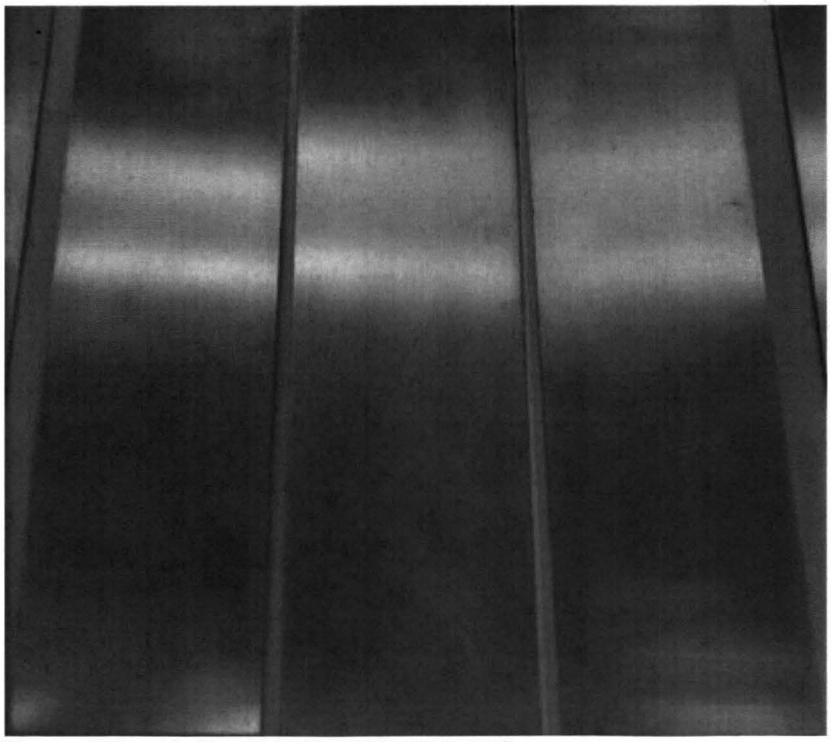

Figure 152 – Alodine T 5900 RTU, 7075-T73

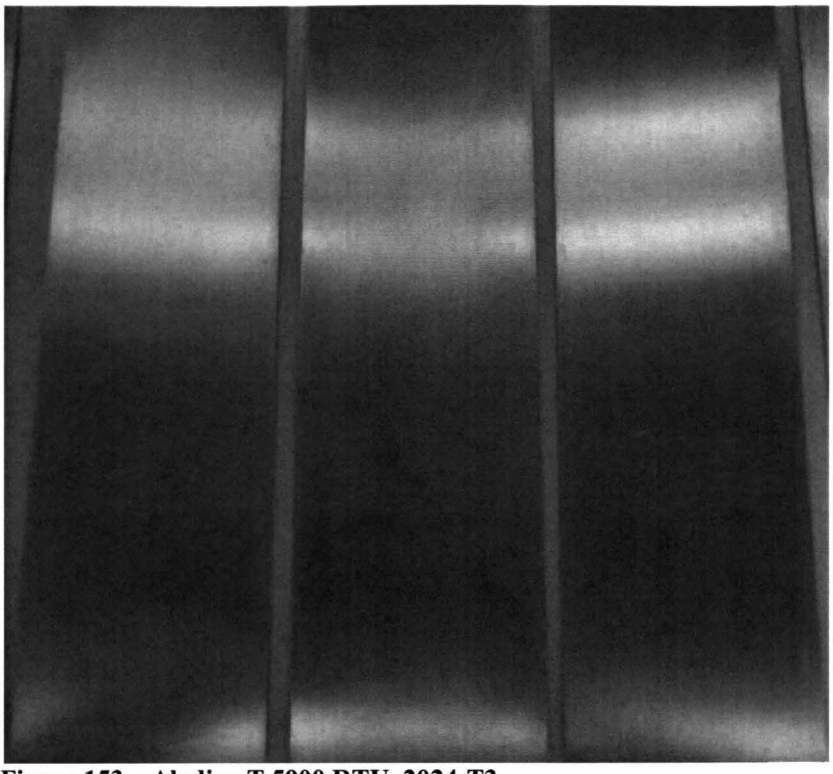

Figure 153 – Alodine T 5900 RTU, 2024-T3

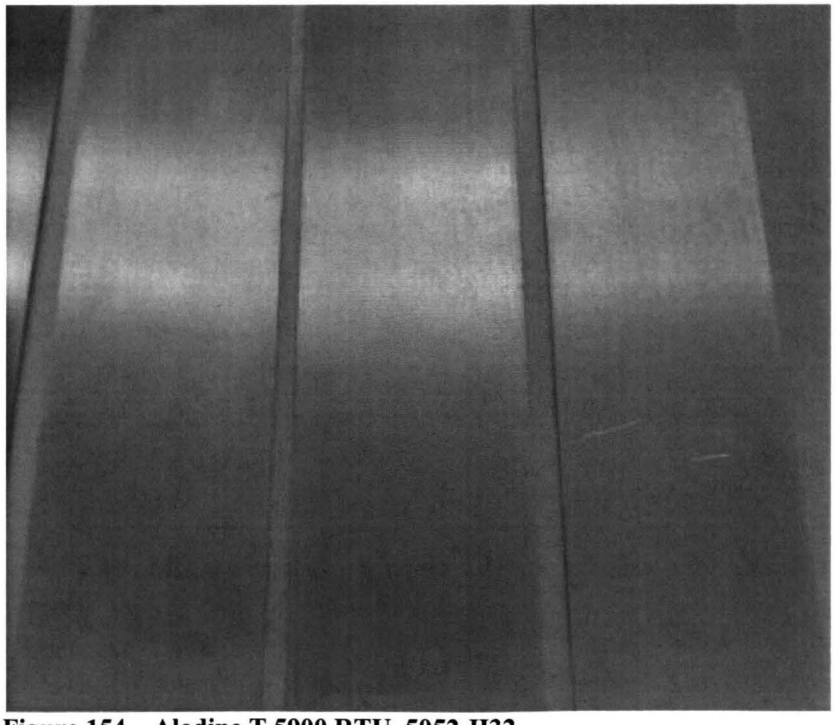

Figure 154 – Alodine T 5900 RTU, 5052-H32

Iridite NCP

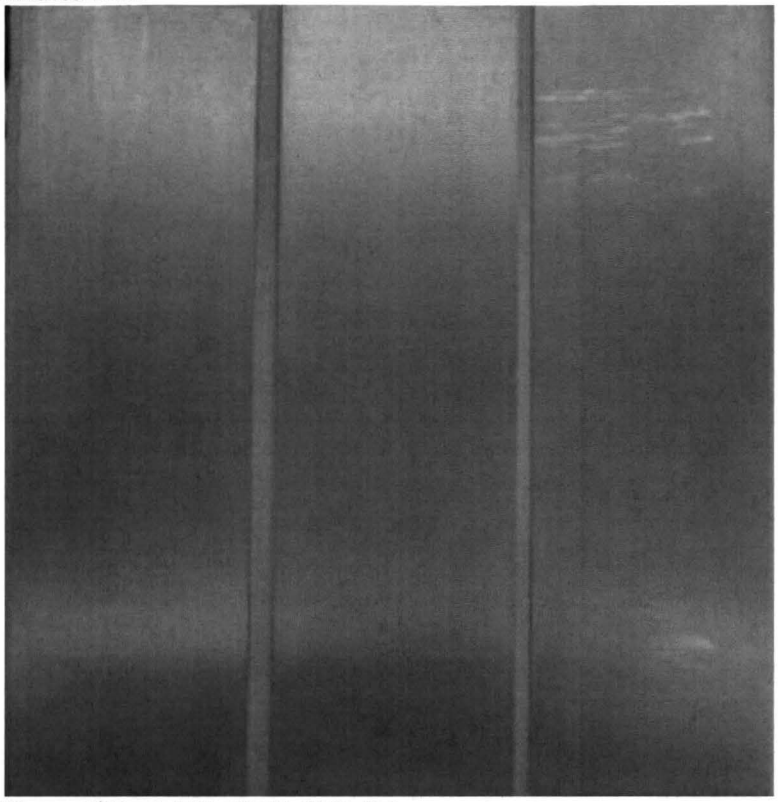

Figure 155 – Iridite NCP, 6061-T6

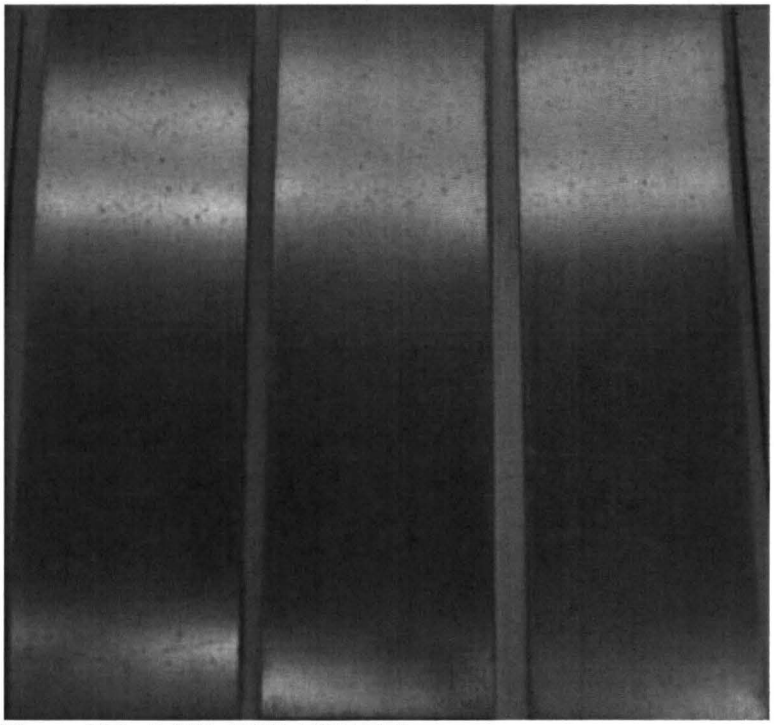

Figure 156 – Iridite NCP, 7075-T73

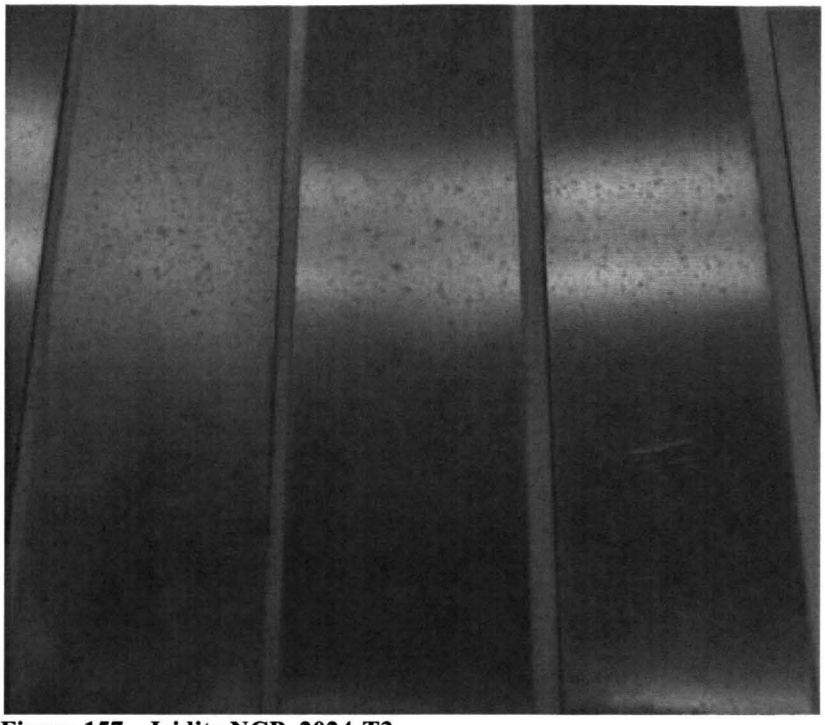

Figure 157 – Iridite NCP, 2024-T3

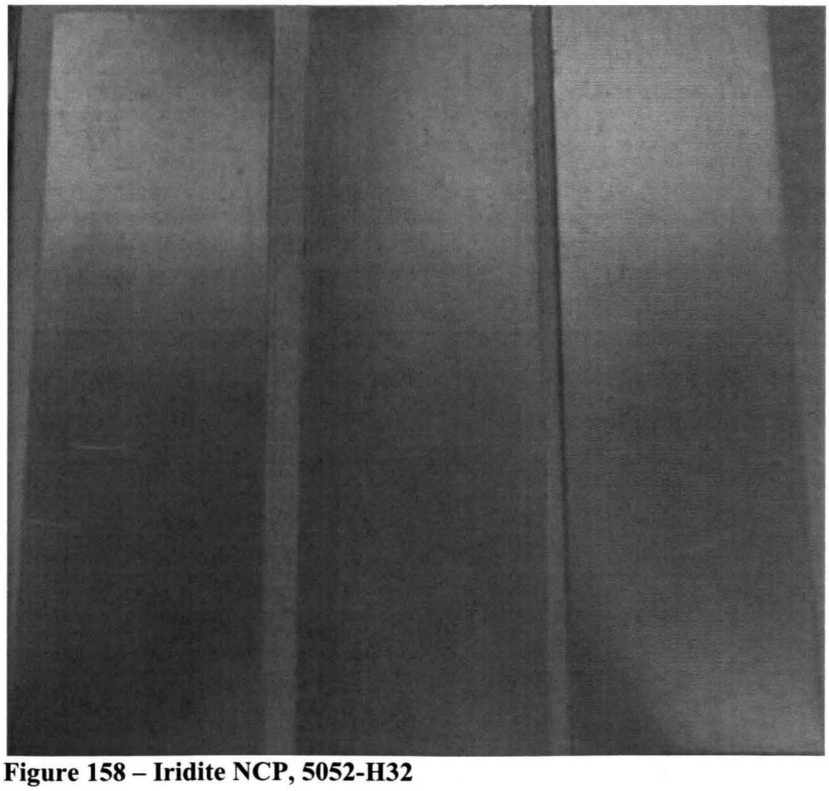

Figure 158 – Iridite NCP, 5052-H32

Metalast HF

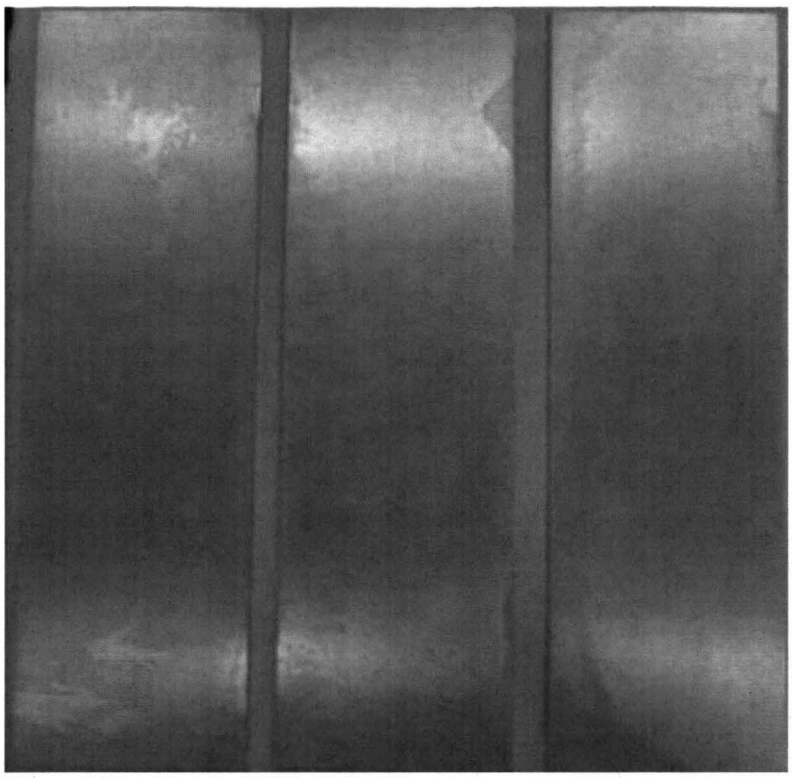

Figure 159 – Metalast HF, 6061-T6

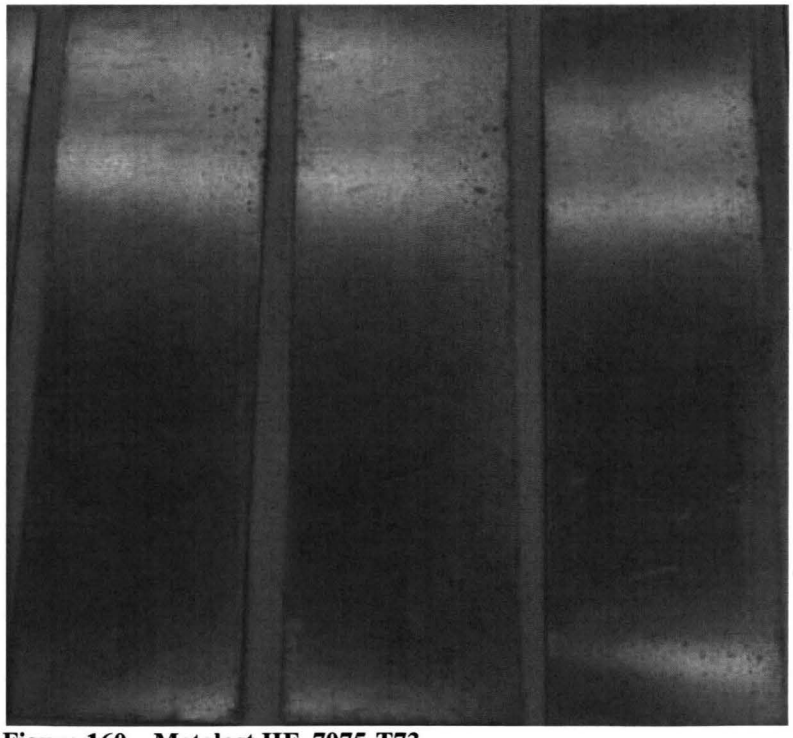

Figure 160 – Metalast HF, 7075-T73

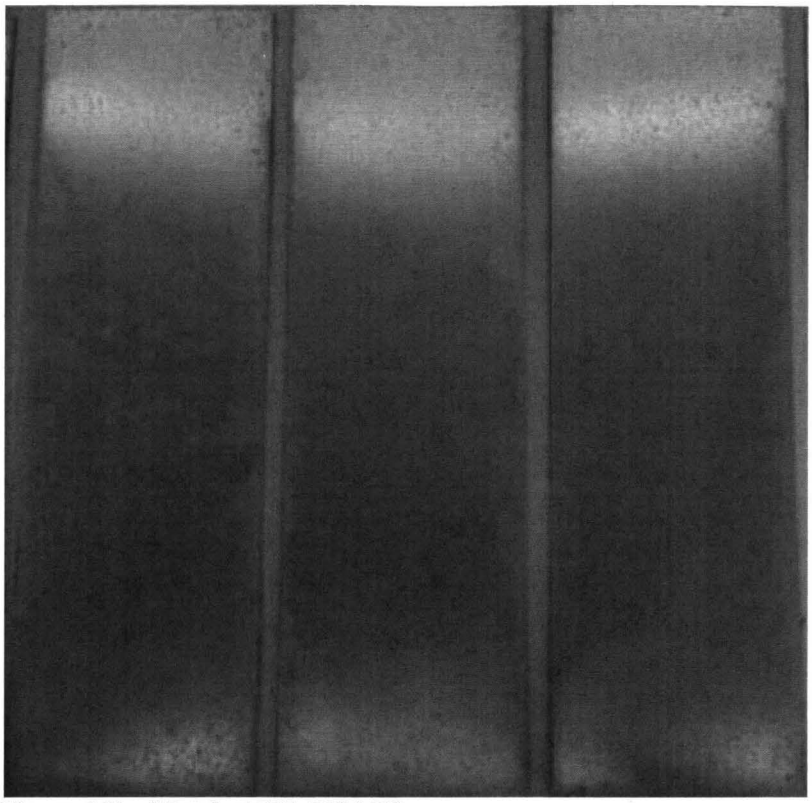

Figure 161 – Metalast HF, 2024-T3

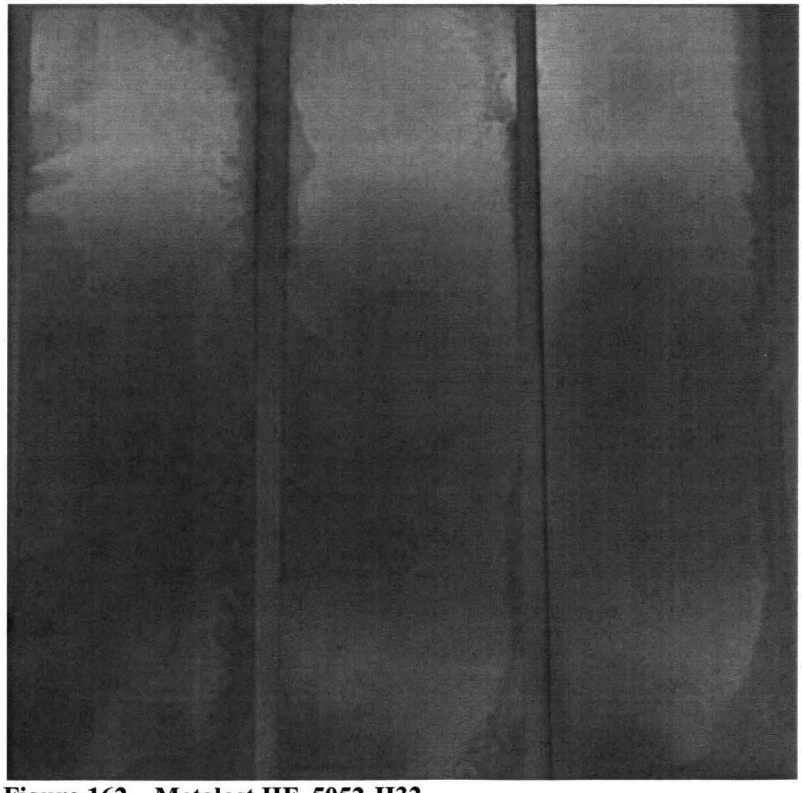

Figure 162 – Metalast HF, 5052-H32

Metalast HF-EPA

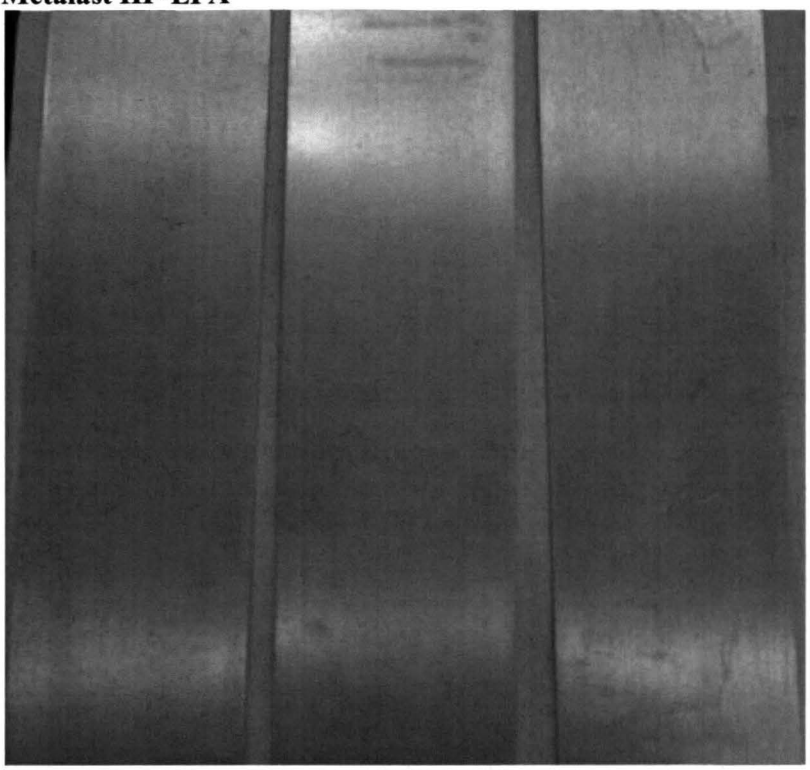

Figure 163 – Metalast HF-EPA, 6061-T6

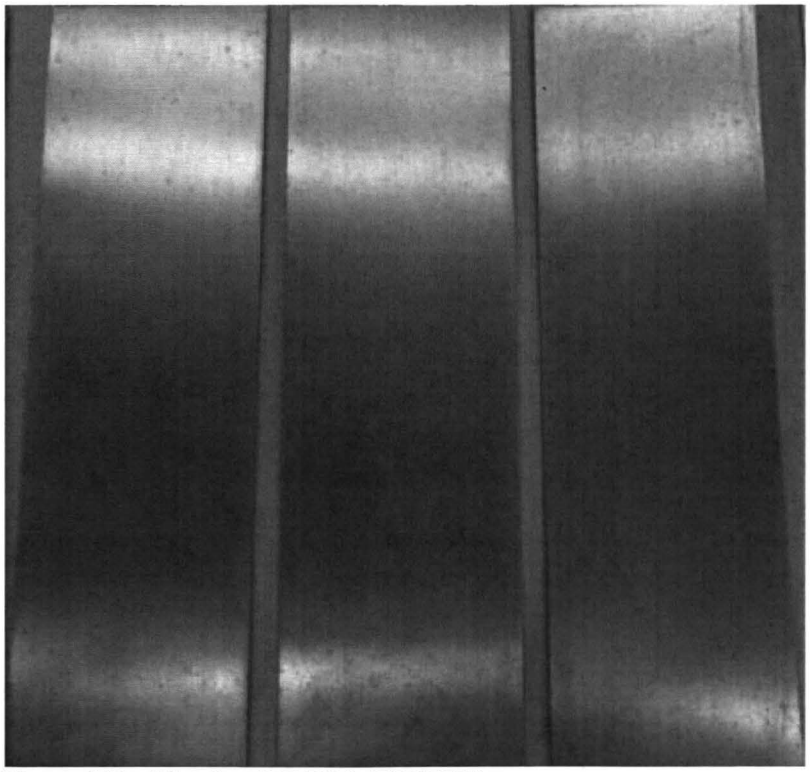

Figure 164 – Metalast HF-EPA, 7075-T73

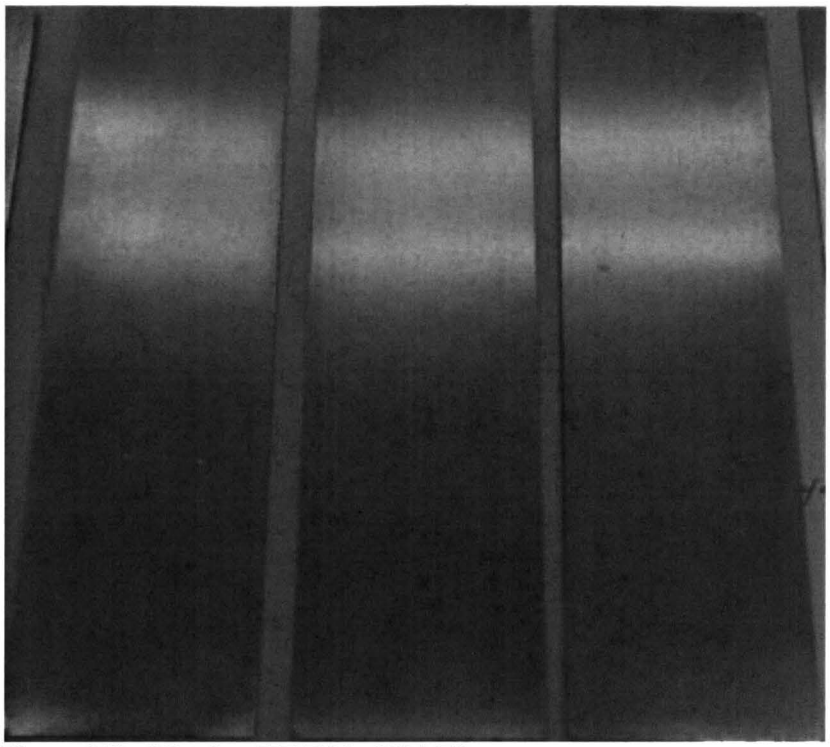

Figure 165 – Metalast HF-EPA, 2024-T3

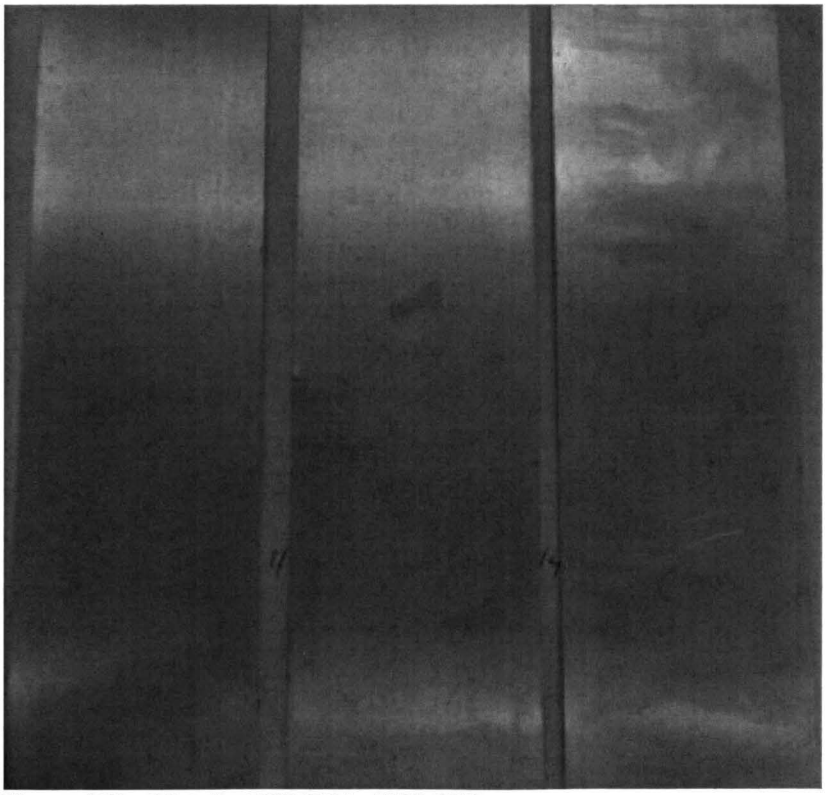

Figure 166 – Metalast HF-EPA, 5052-H32

SurTec 650

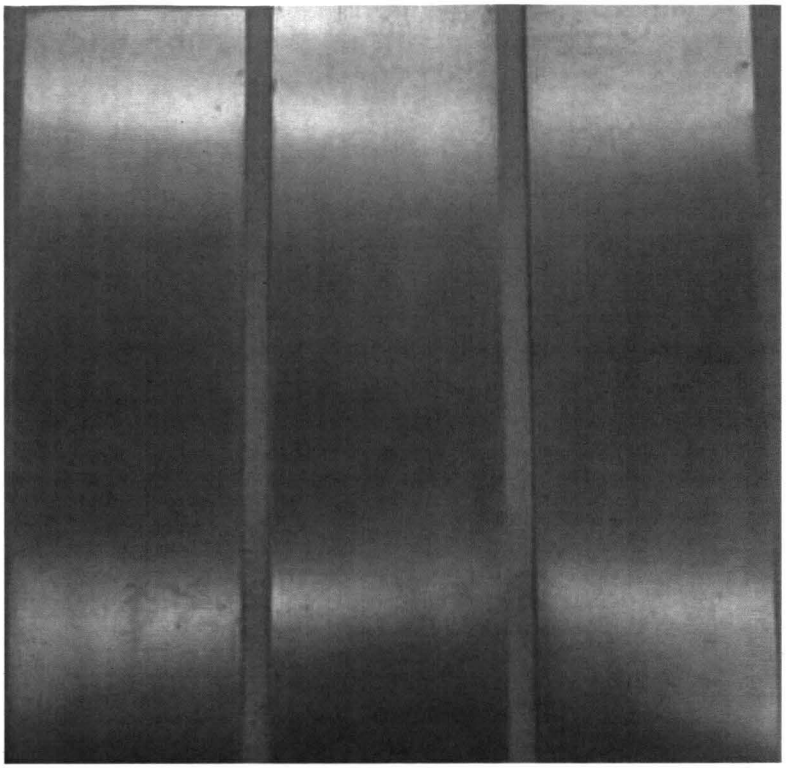

Figure 167 – SurTec 650, 6061-T6

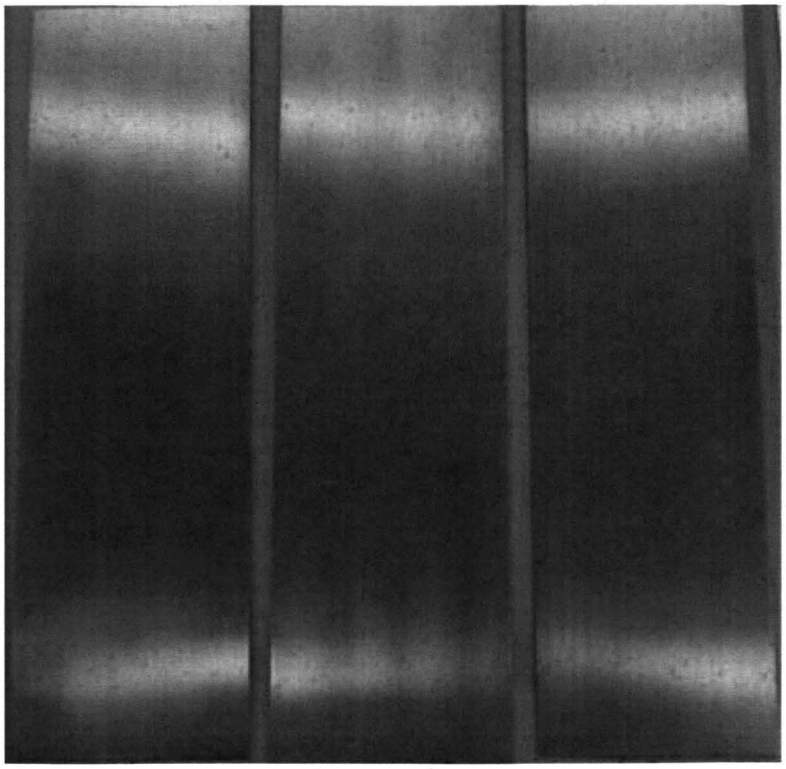

Figure 168 – SurTec 650, 7075-T73

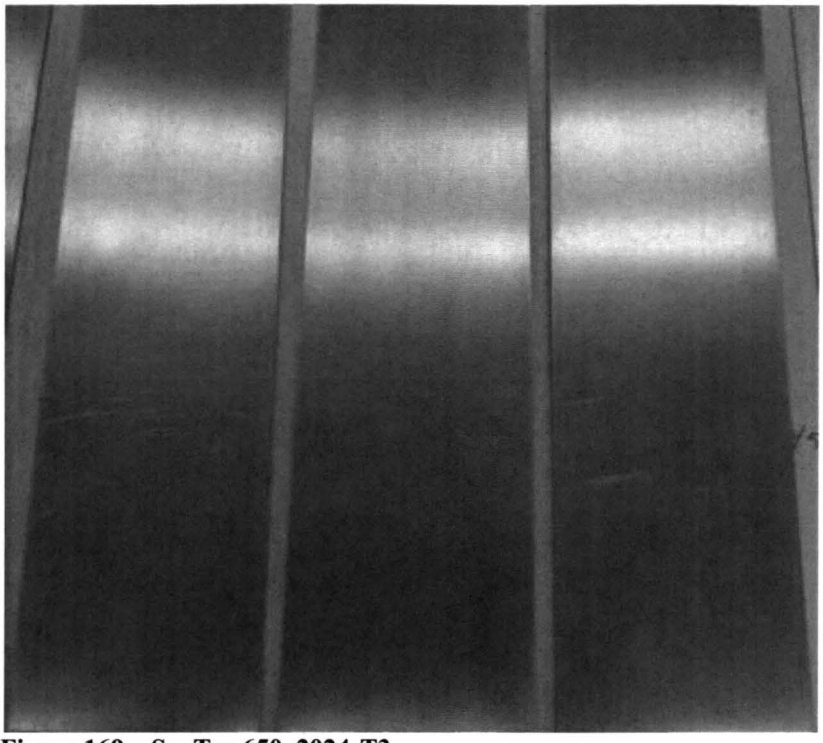

Figure 169 – SurTec 650, 2024-T3

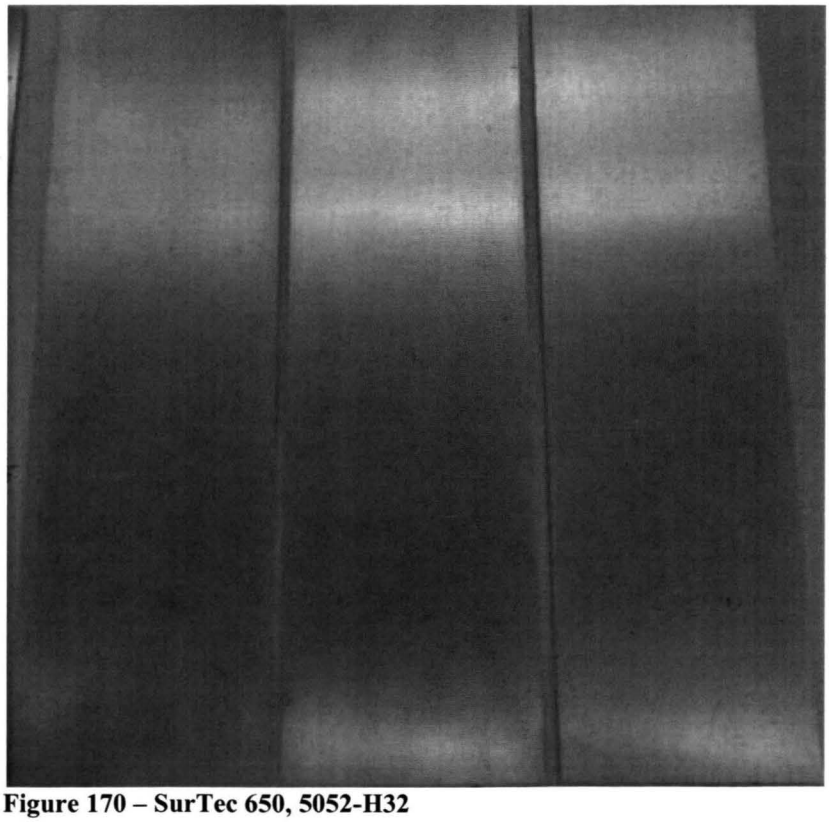

Figure 170 – SurTec 650, 5052-H32

SurTec 650C

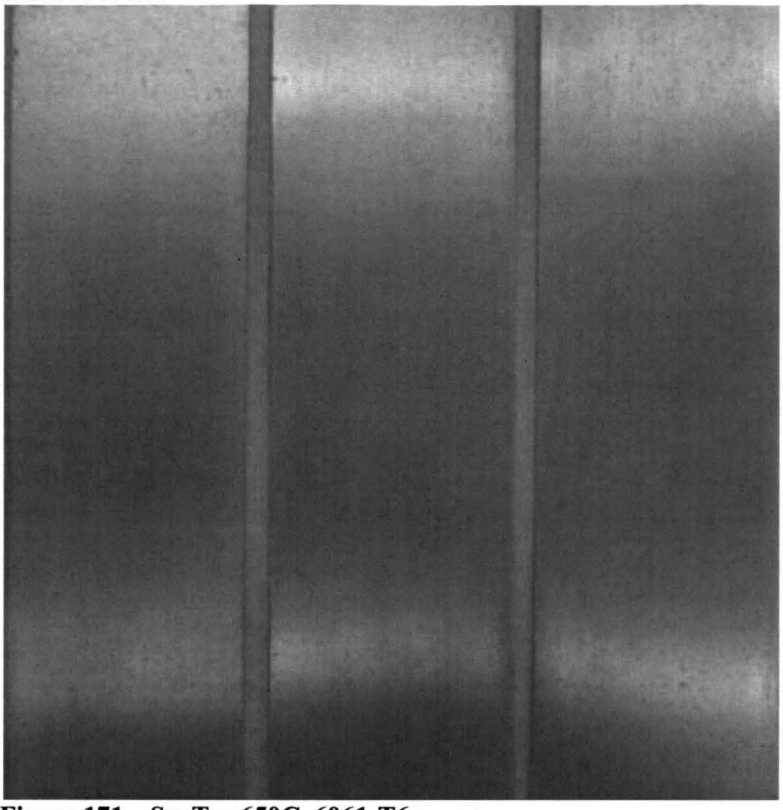

Figure 171 – SurTec 650C, 6061-T6

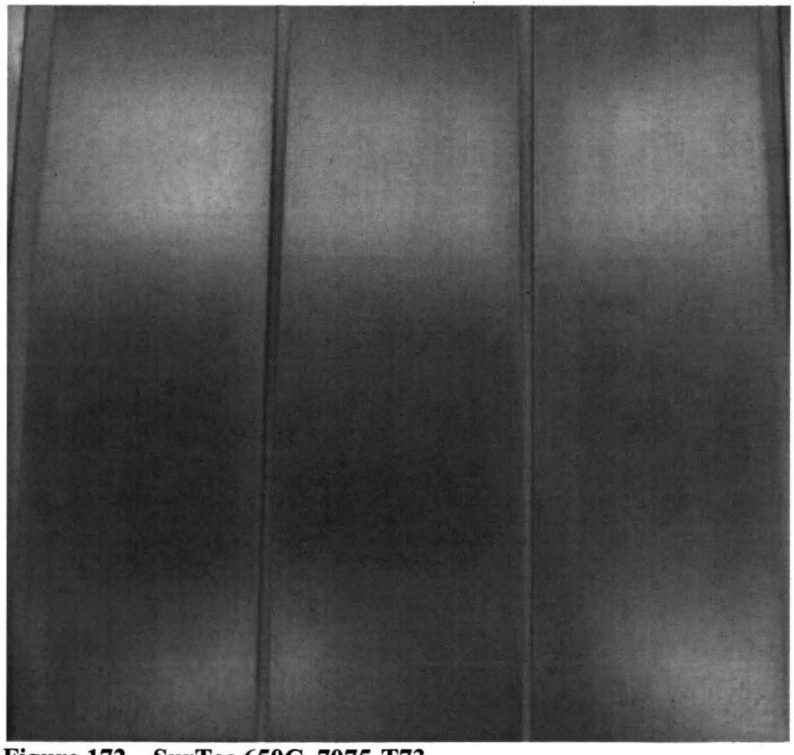

Figure 172 – SurTec 650C, 7075-T73

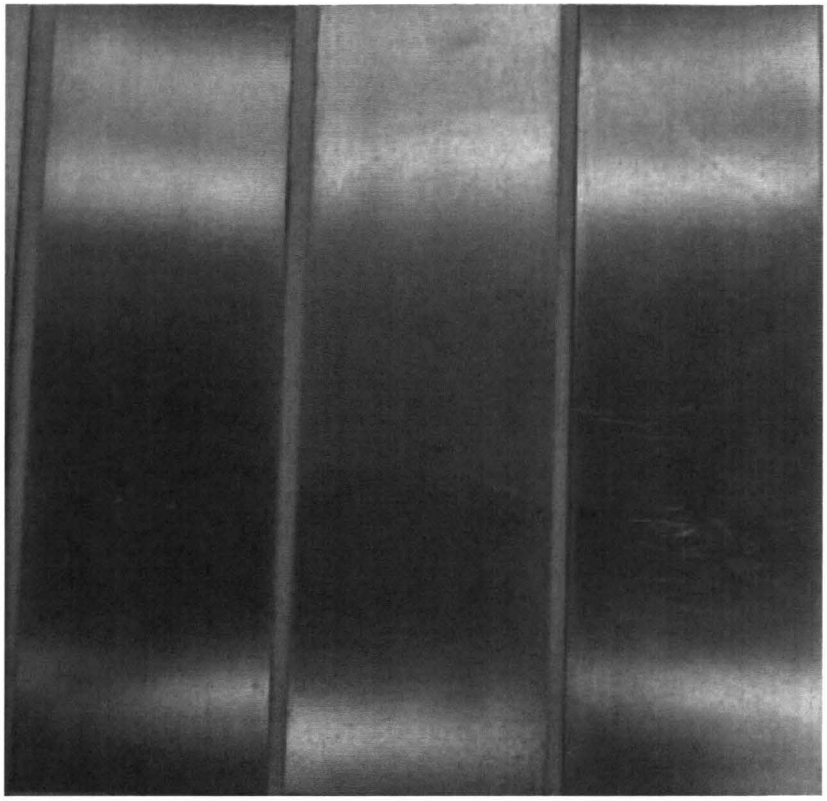

Figure 173 – SurTec 650C, 2024-T3

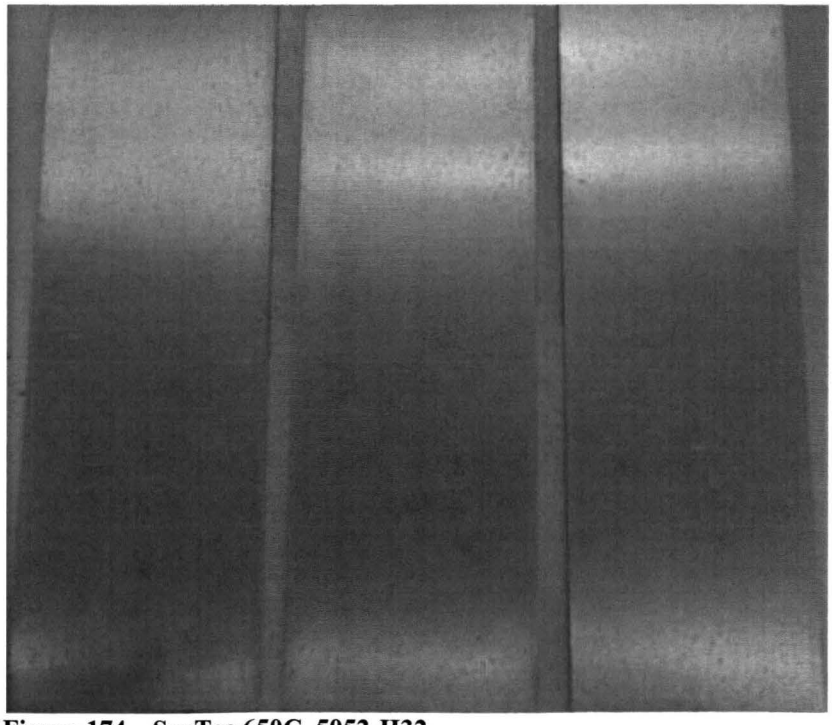

Figure 174 – SurTec 650C, 5052-H32

Appendix F –
Panel Photographs - PATTI JR Pull Test

Alodine T 5900 RTU – PPG CA7233

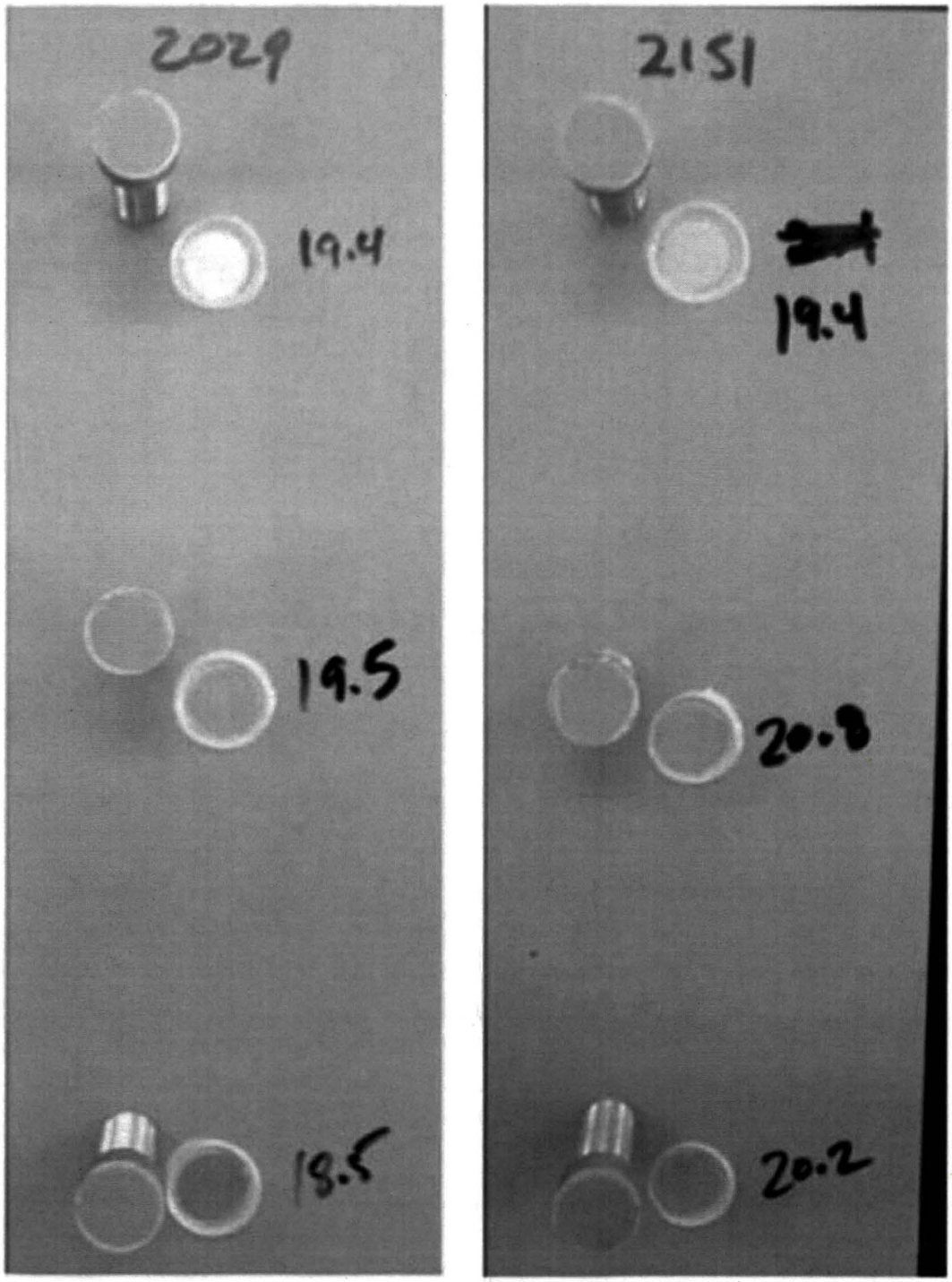

Figure 175 – Alodine T 5900 RTU; 6061-T6 (Left), 5052-H32 (Right)

Iridite NCP - PPG CA7233

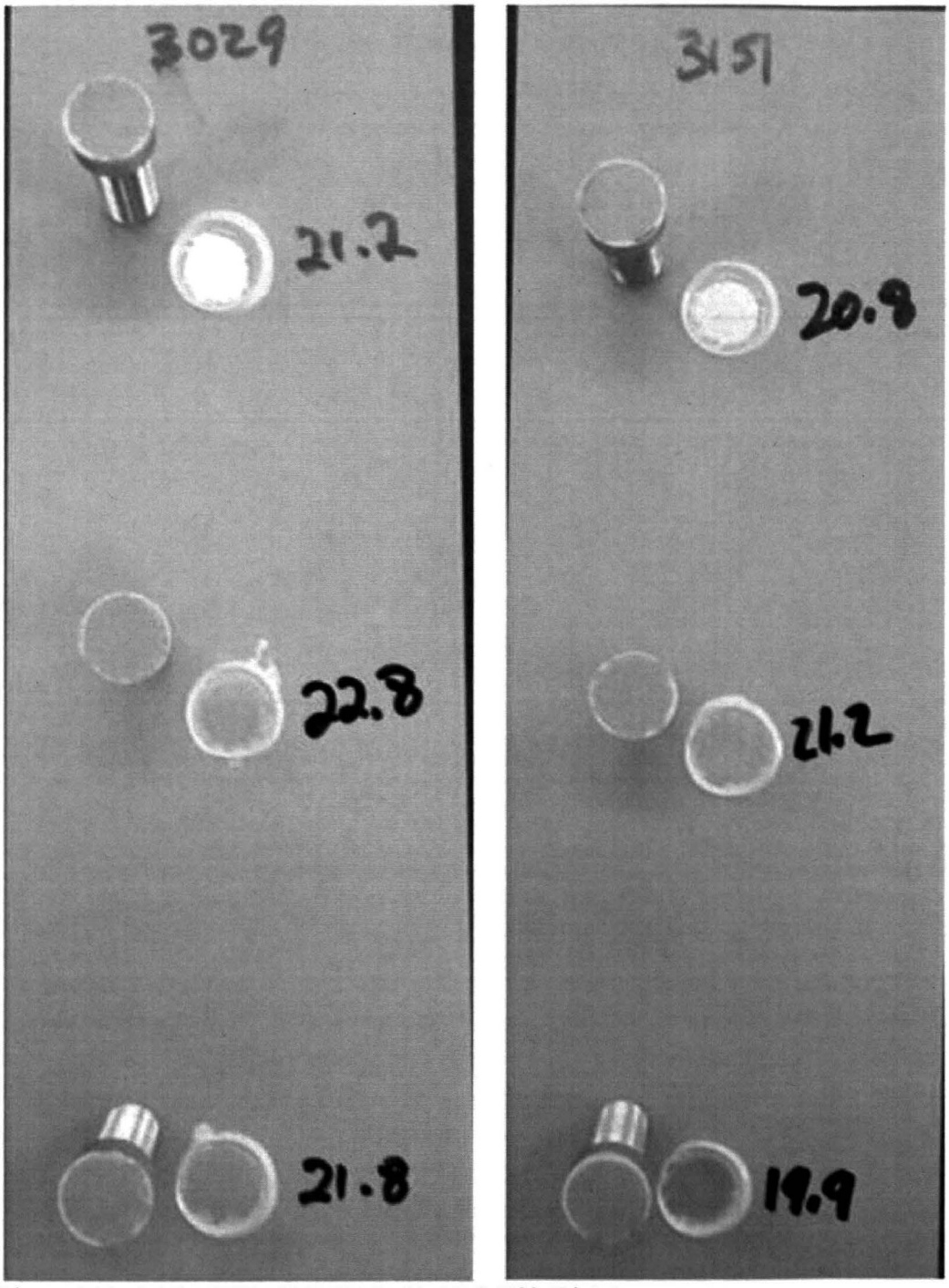

Figure 176 – Iridite NCP; 6061-T6 (Left), 5052-H32 (Right)

Metalast HF - PPG CA7233

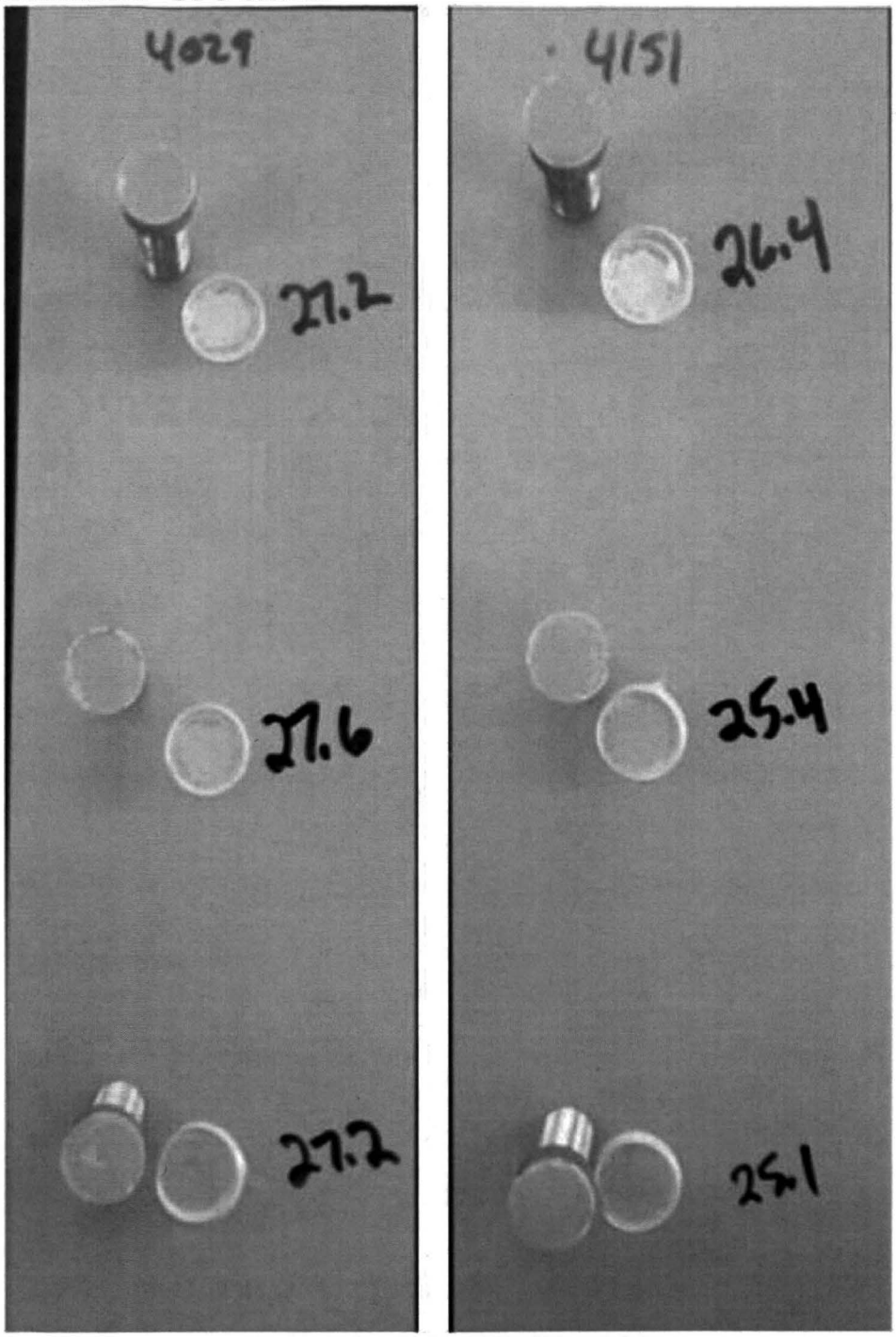

Figure 177 – Metalast HF; 6061-T6 (Left), 5052-H32 (Right)

Metalast HF-EPA - PPG CA7233

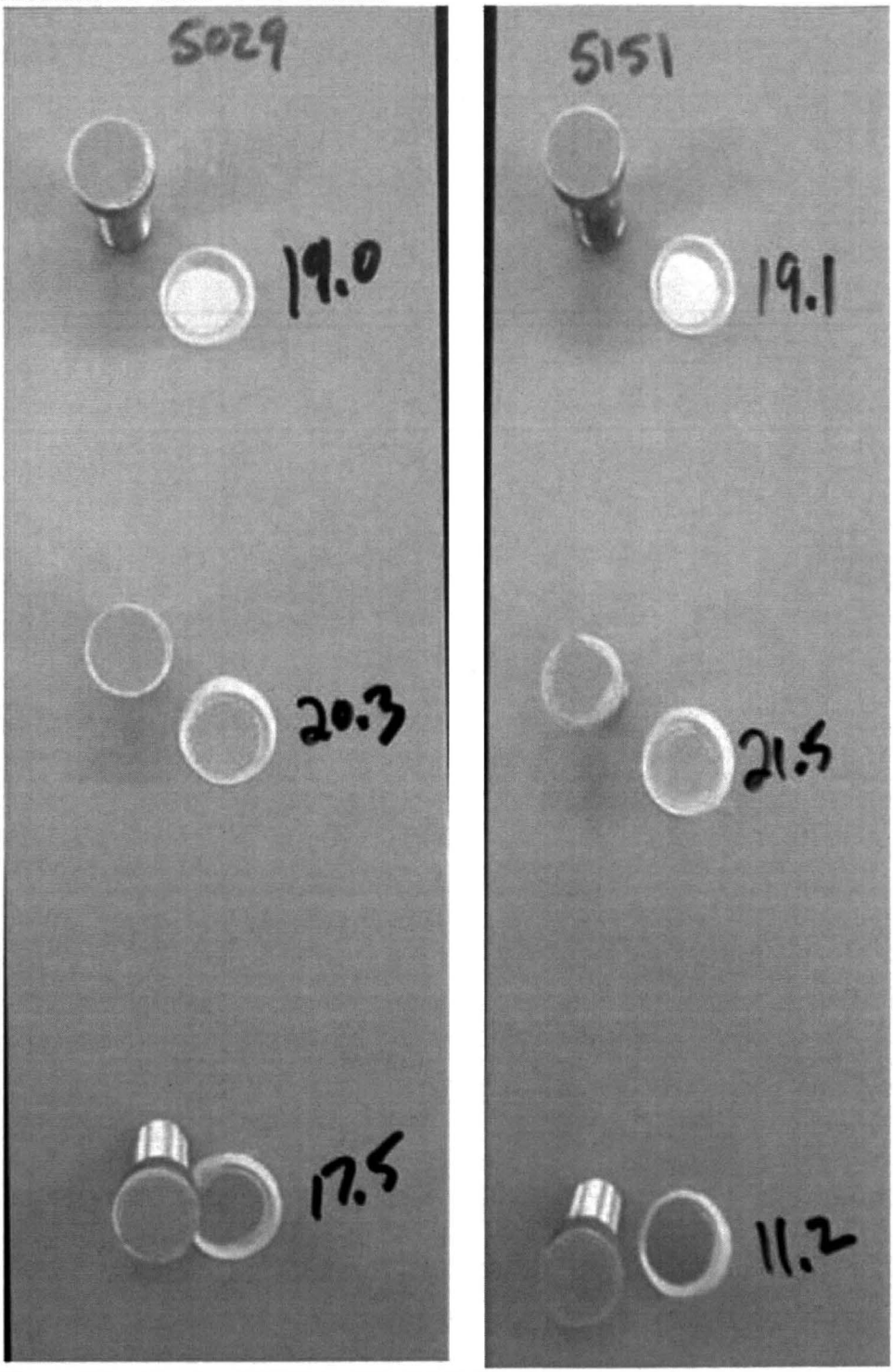

Figure 178 – Metalast HF-EPA; 6061-T6 (Left), 5052-H32 (Right)

SurTec 650 - PPG CA7233

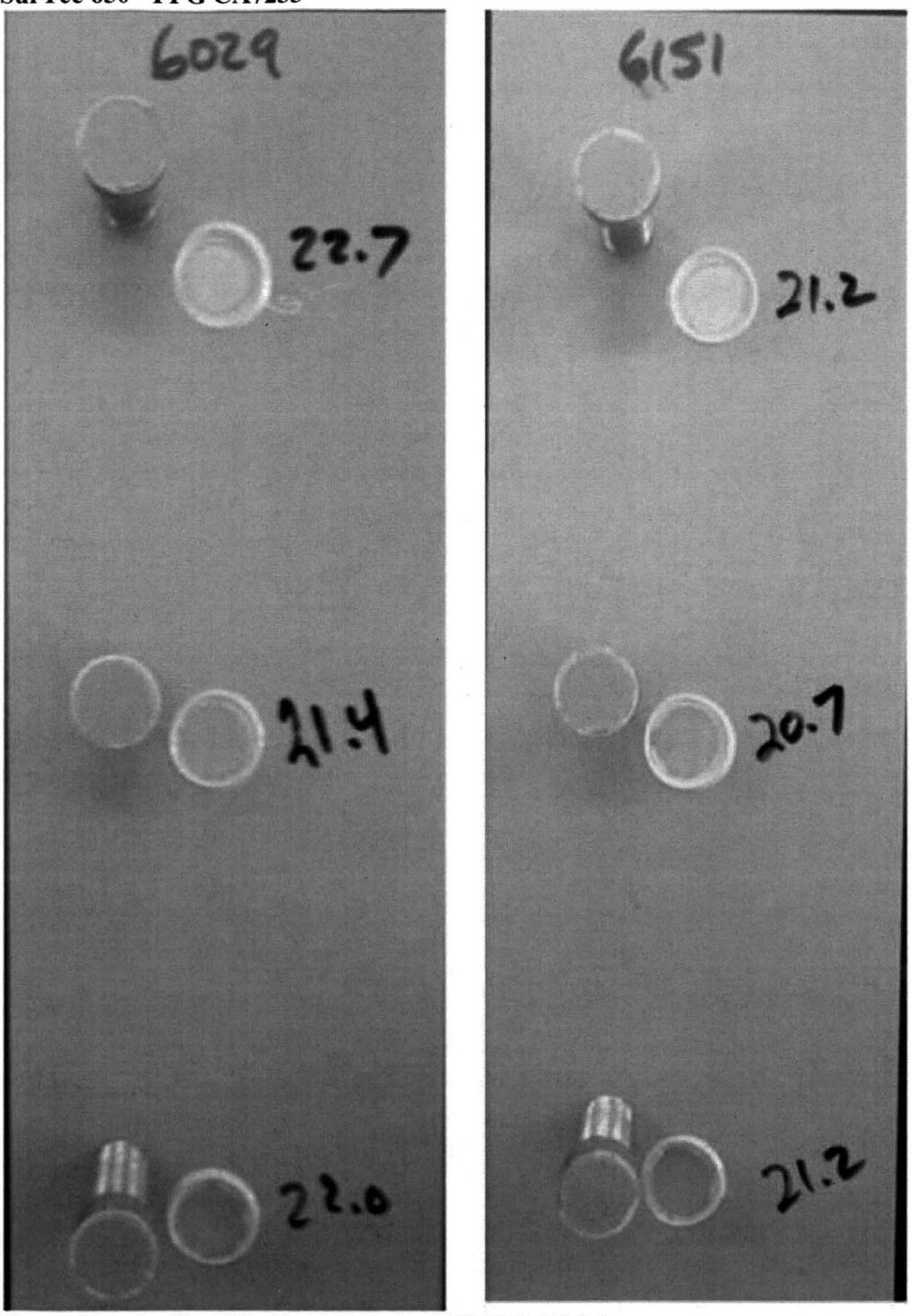

Figure 179 – SurTec 650; 6061-T6 (Left), 5052-H32 (Right)

SurTec 650C - PPG CA7233

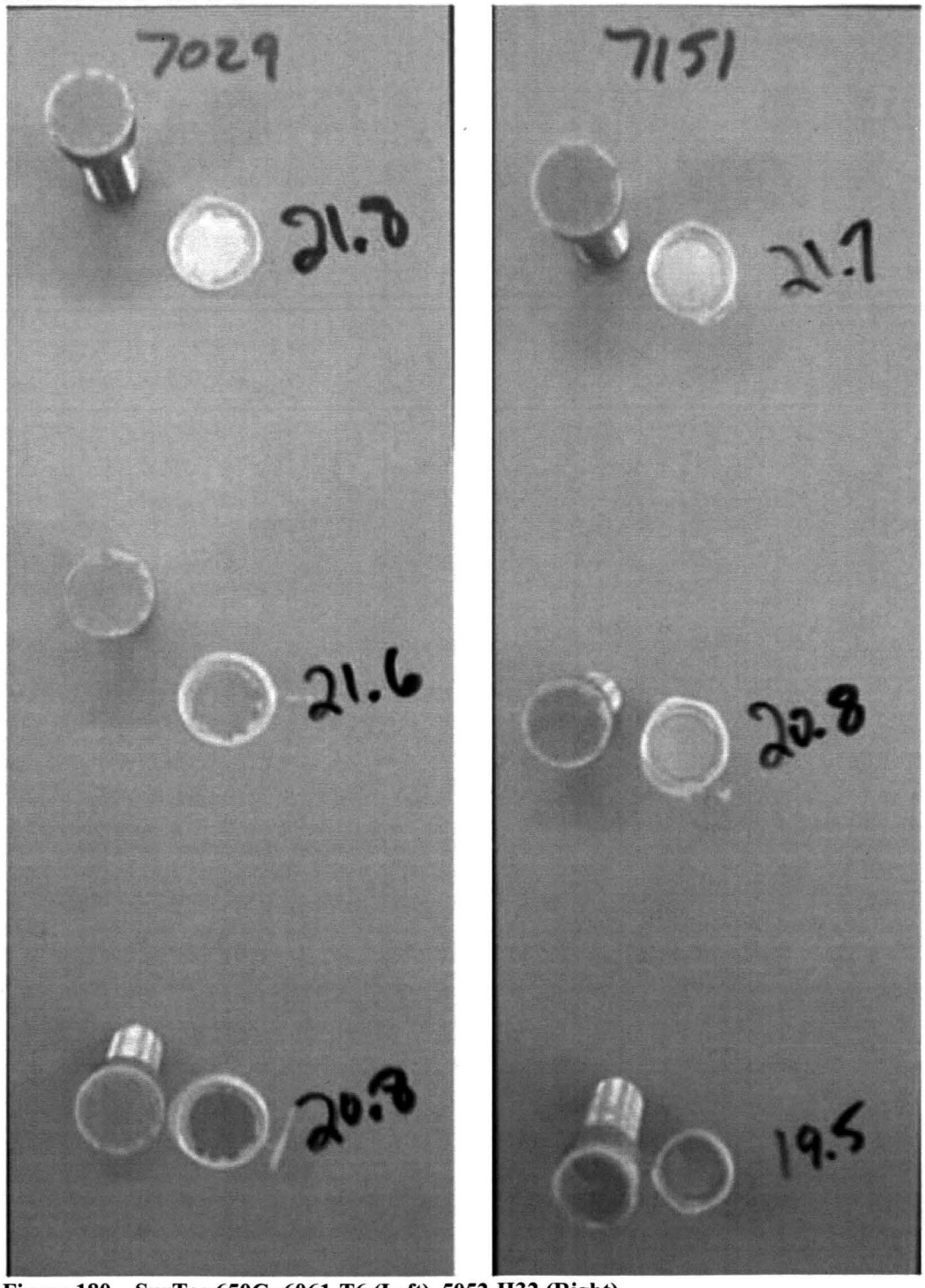

Figure 180 – SurTec 650C; 6061-T6 (Left), 5052-H32 (Right)

Alodine T 5900 RTU - Deft 44-GN-07A

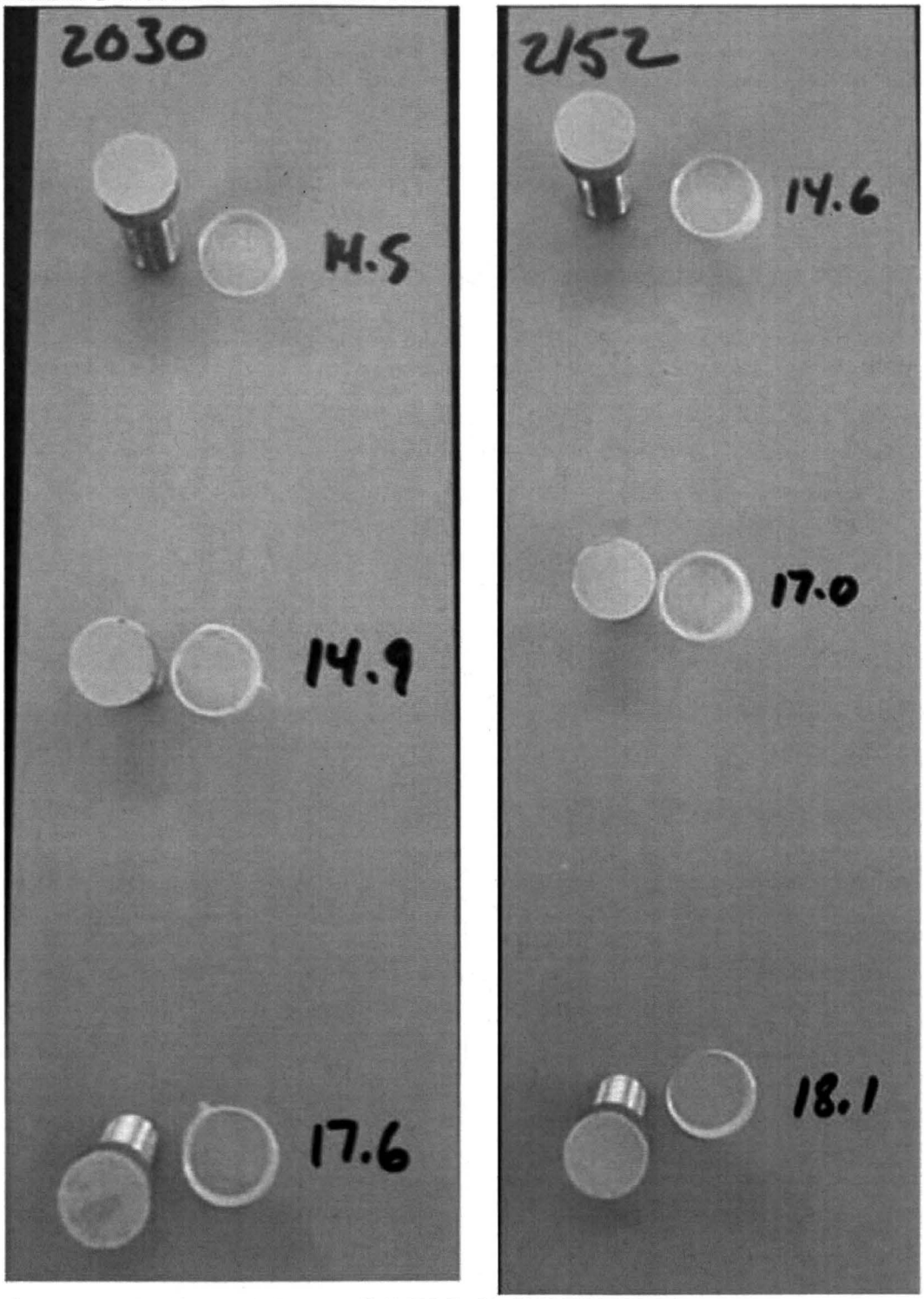

Figure 181 – Alodine T 5900 RTU; 6061-T6 (Left), 5052-H32 (Right)

Iridite NCP - Deft 44-GN-07A

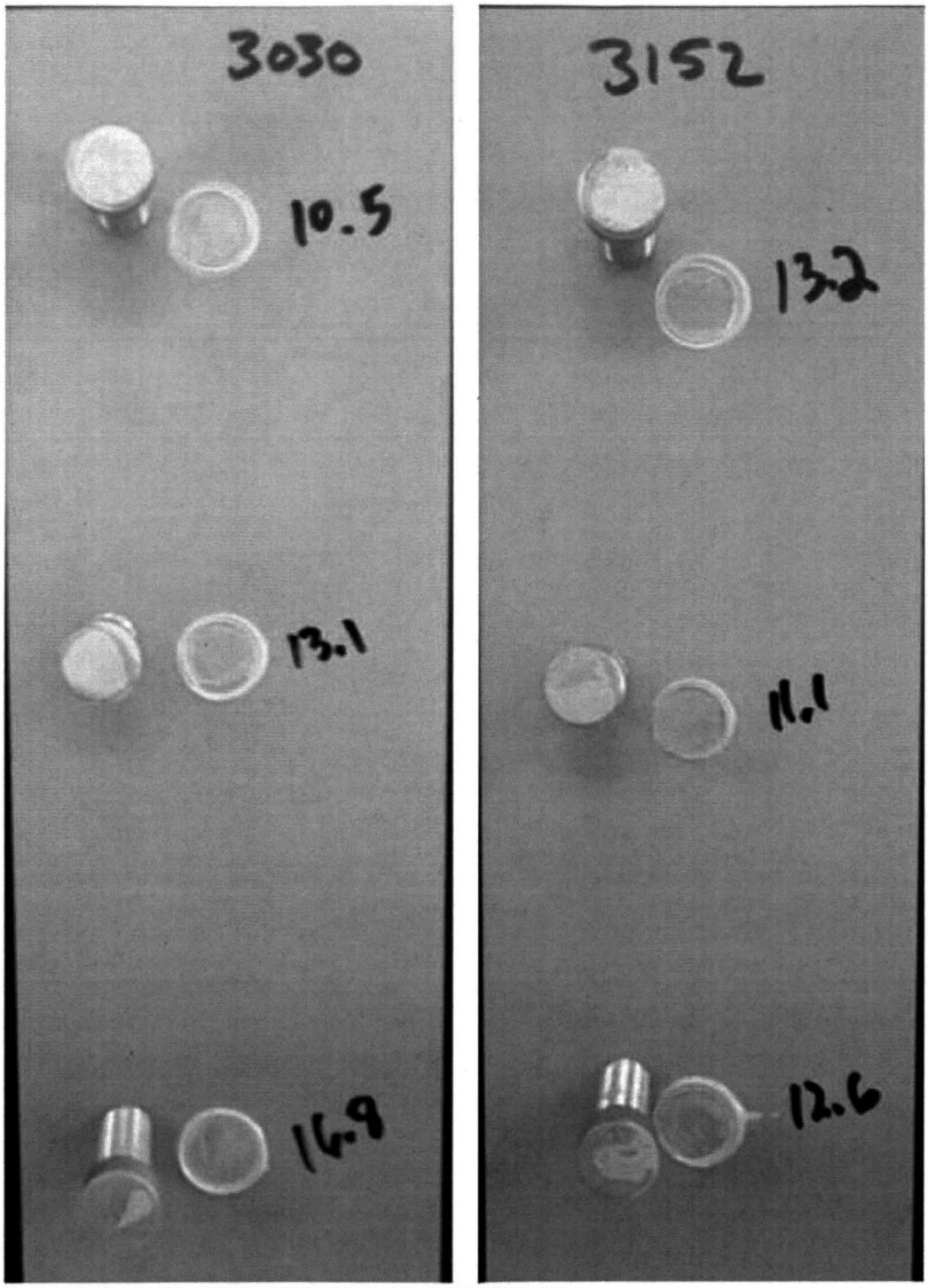

Figure 182 – Iridite NCP; 6061-T6 (Left), 5052-H32 (Right)

Metalast HF - Deft 44-GN-07A

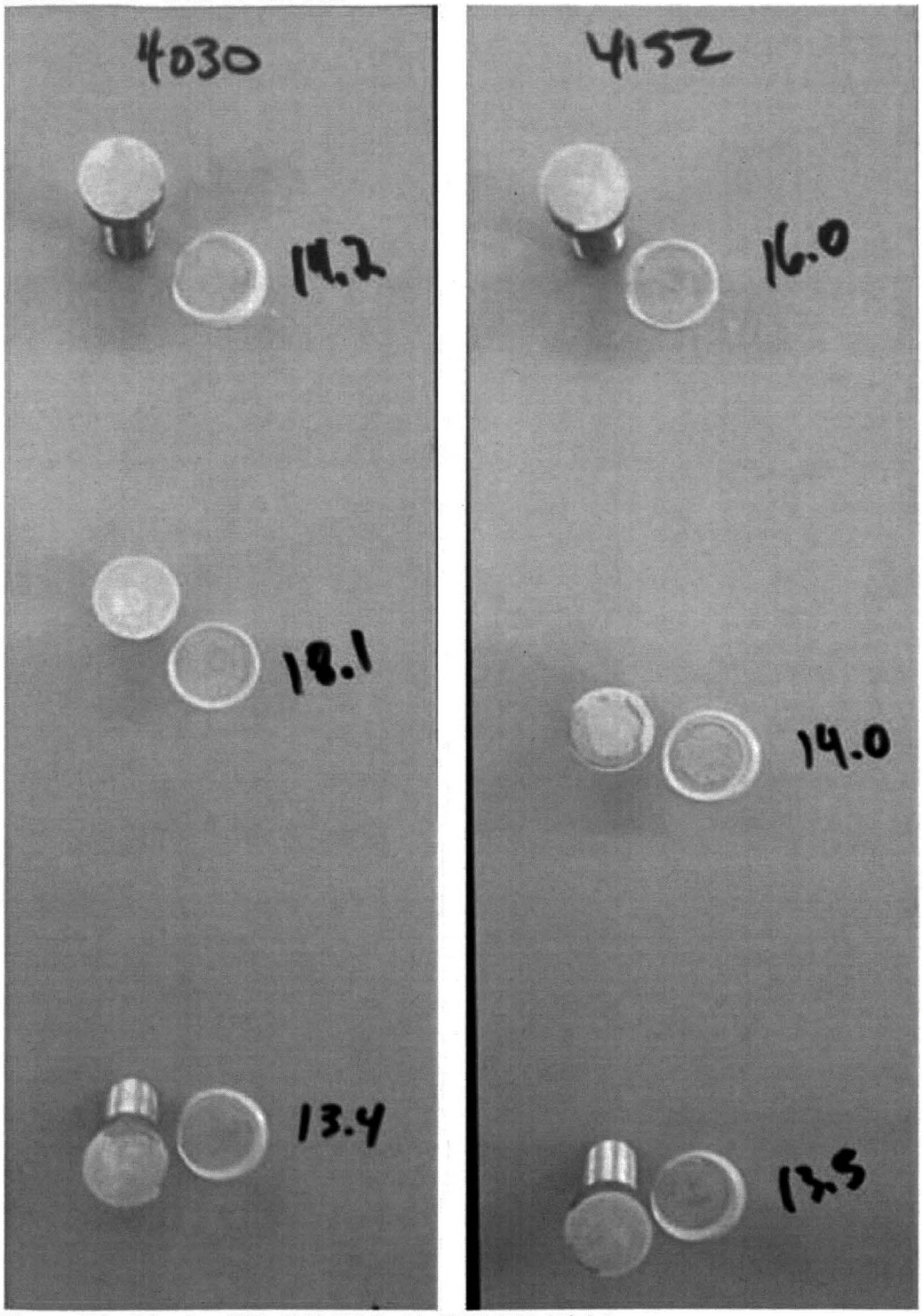

Figure 183 – Metalast HF; 6061-T6 (Left), 5052-H32 (Right)

Metalast HF-EPA - Deft 44-GN-07A

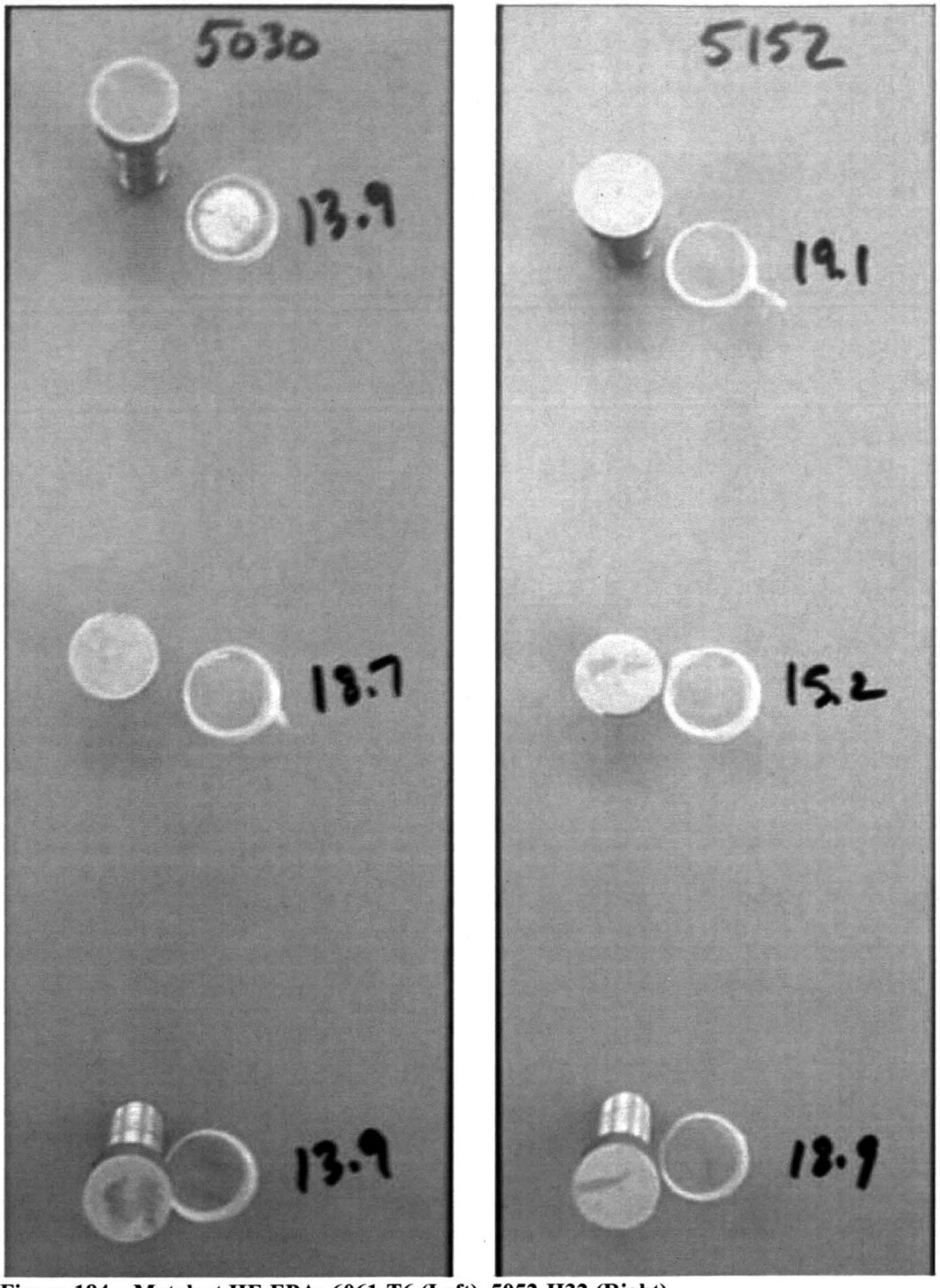

Figure 184 – Metalast HF-EPA; 6061-T6 (Left), 5052-H32 (Right)

SurTec 650 - Deft 44-GN-07A

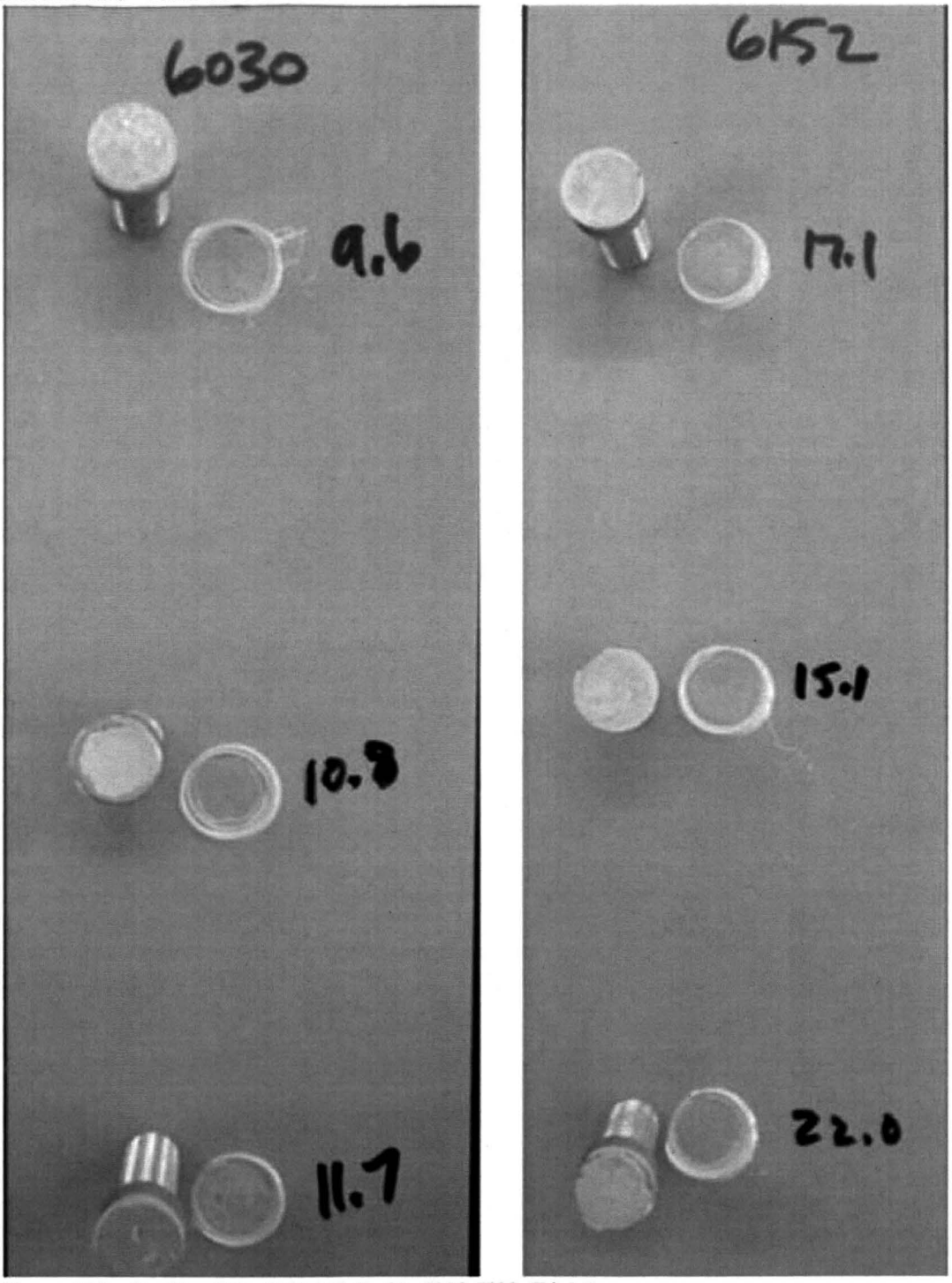

Figure 185 – SurTec 650; 6061-T6 (Left), 5052-H32 (Right)

SurTec 650C - Deft 44-GN-07A

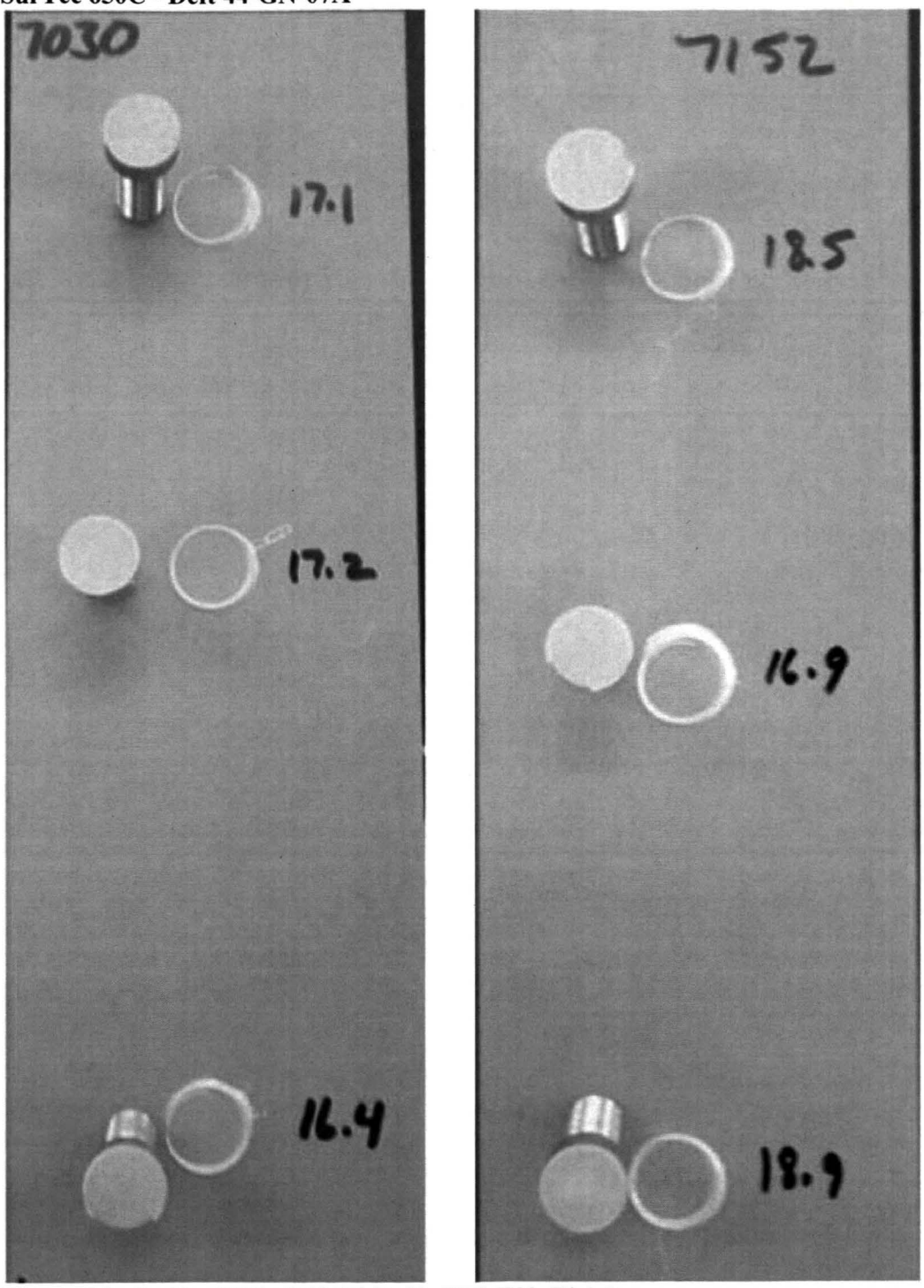

Figure 186 – SurTec 650C; 6061-T6 (Left), 5052-H32 (Right)

Appendix G –
Panel Photographs – Cross-Cut Adhesion ASTM D 3359, Test Method B Ratings

Alodine T 5900 RTU - PPG CA7233 - PPG CA9311

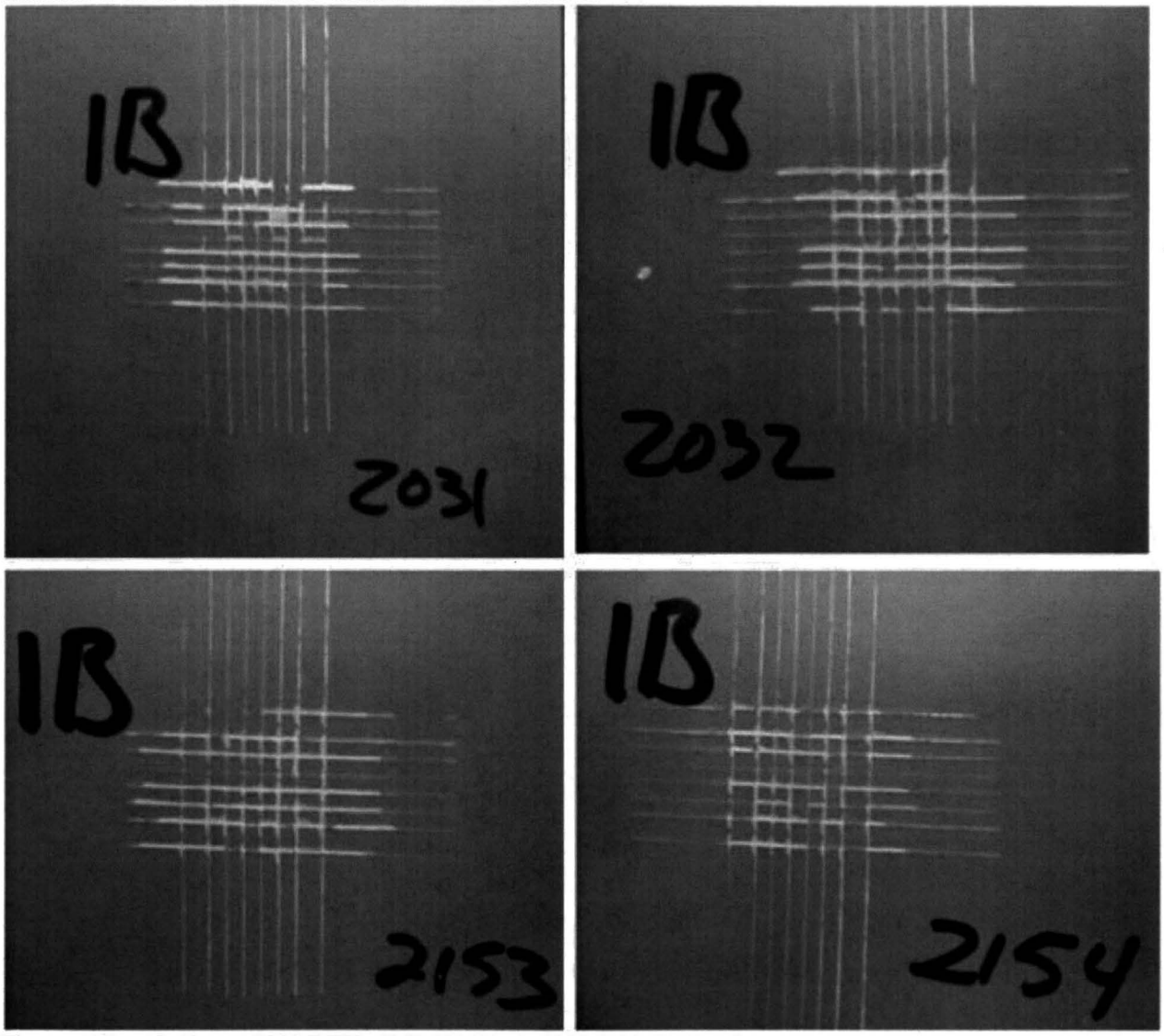

Figure 187 – Alodine T 5900 RTU; 6061-T6 (Top), 5052-H32 (Bottom)

Iridite NCP - PPG CA7233 - PPG CA9311

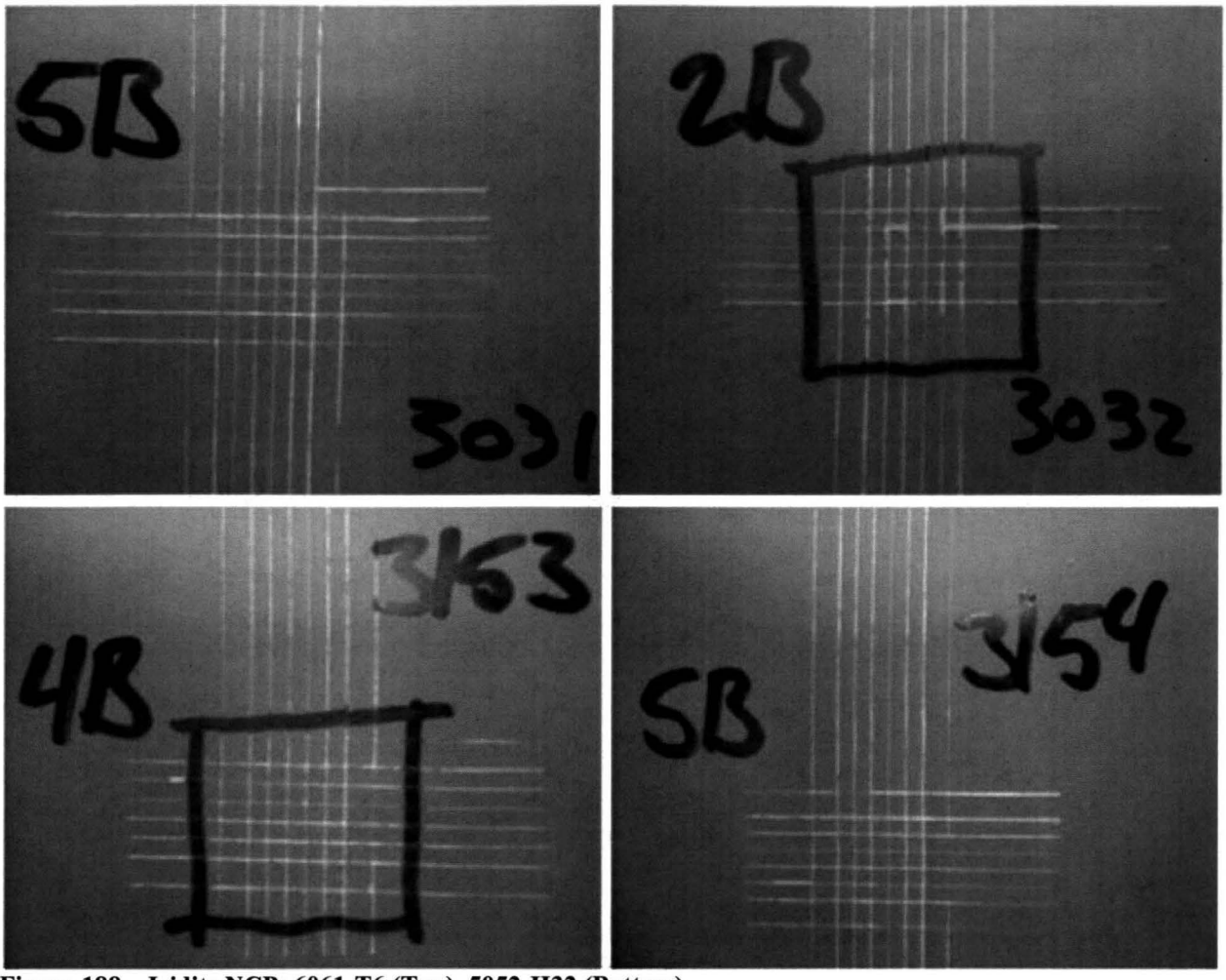

Figure 188 – Iridite NCP; 6061-T6 (Top), 5052-H32 (Bottom)

Metalast HF - PPG CA7233 - PPG CA9311

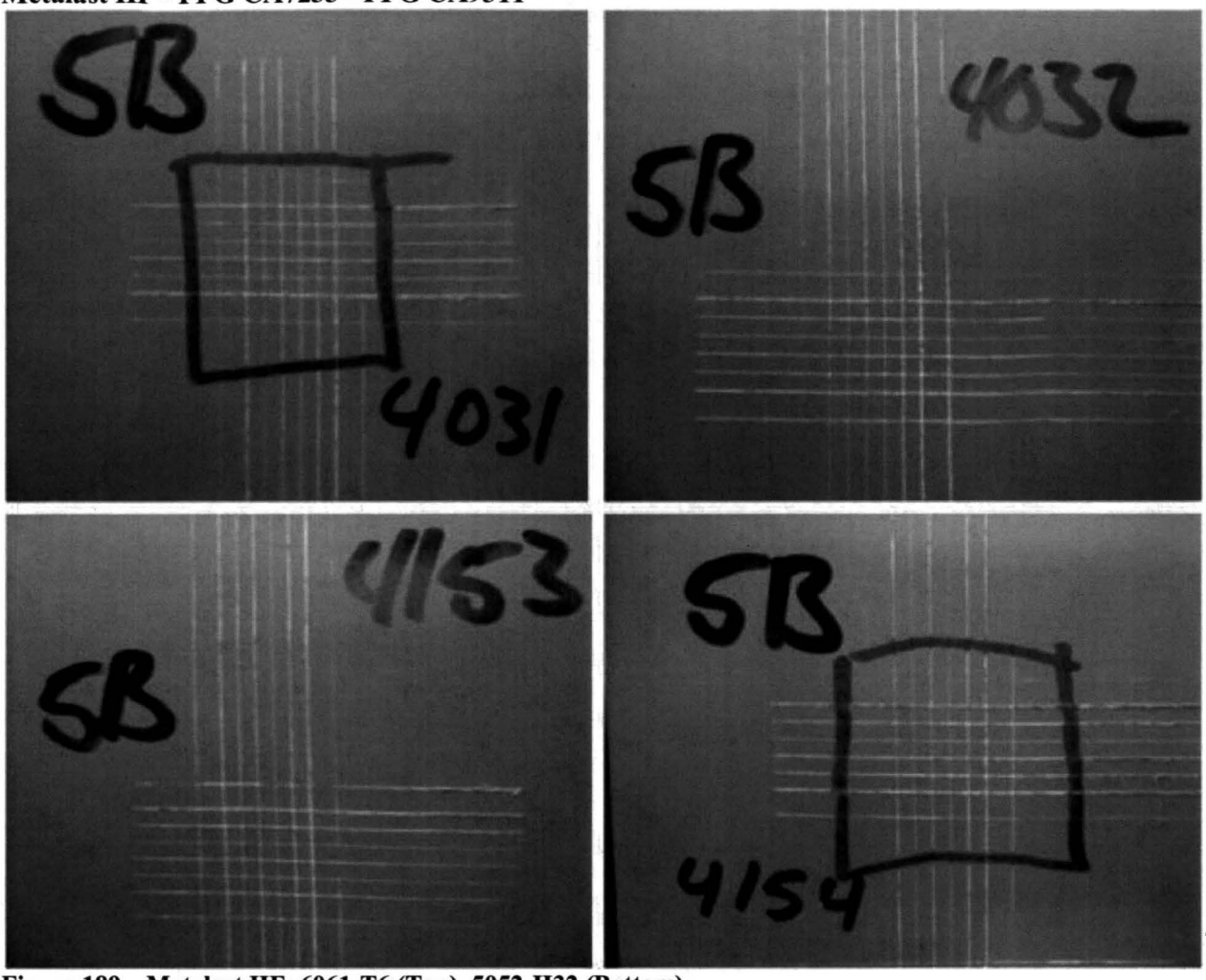

Figure 189 – Metalast HF; 6061-T6 (Top), 5052-H32 (Bottom)

Metalast HF-EPA - PPG CA7233 - PPG CA9311

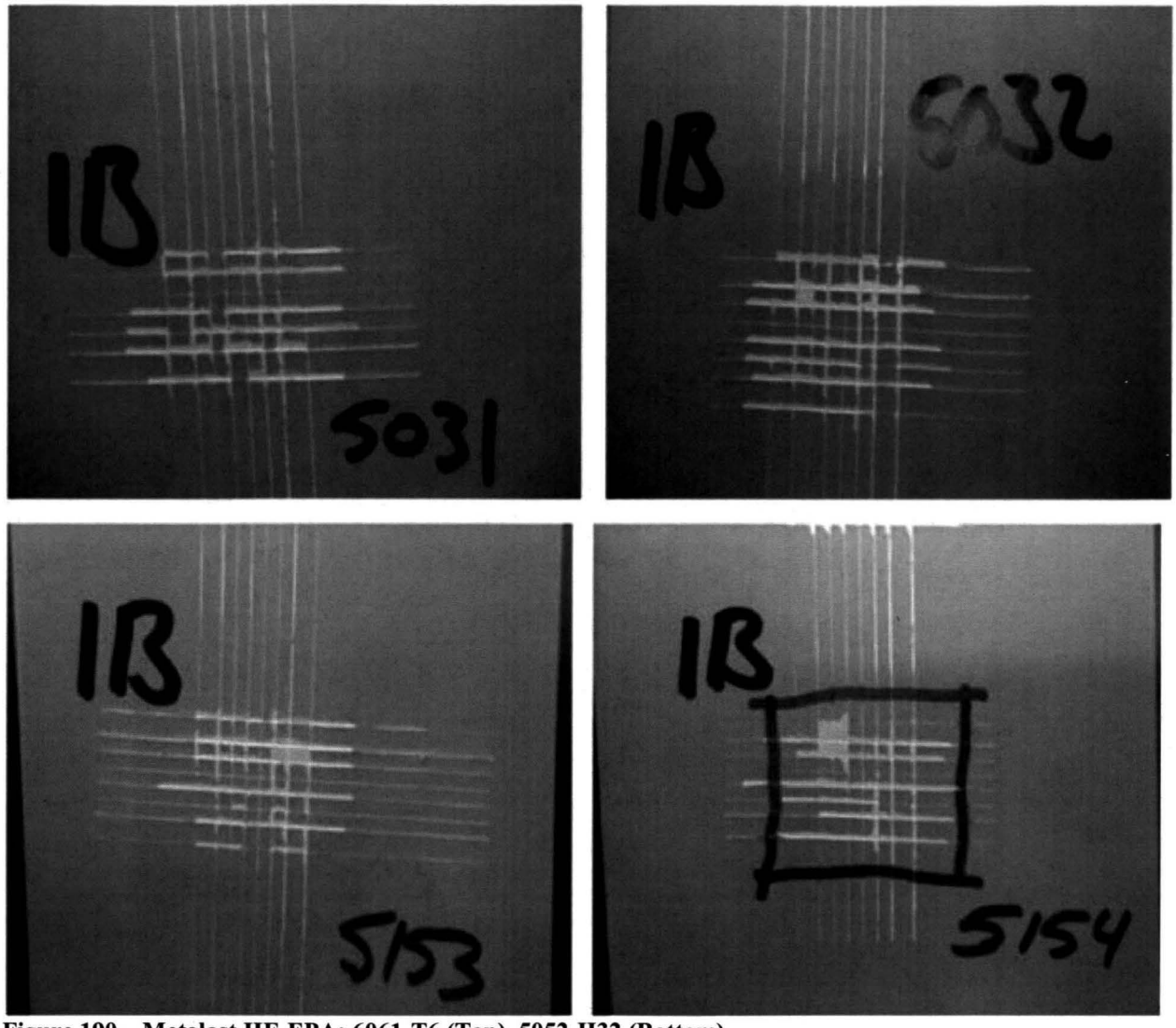

Figure 190 – Metalast HF-EPA; 6061-T6 (Top), 5052-H32 (Bottom)

SurTec 650 - PPG CA7233 - PPG CA9311

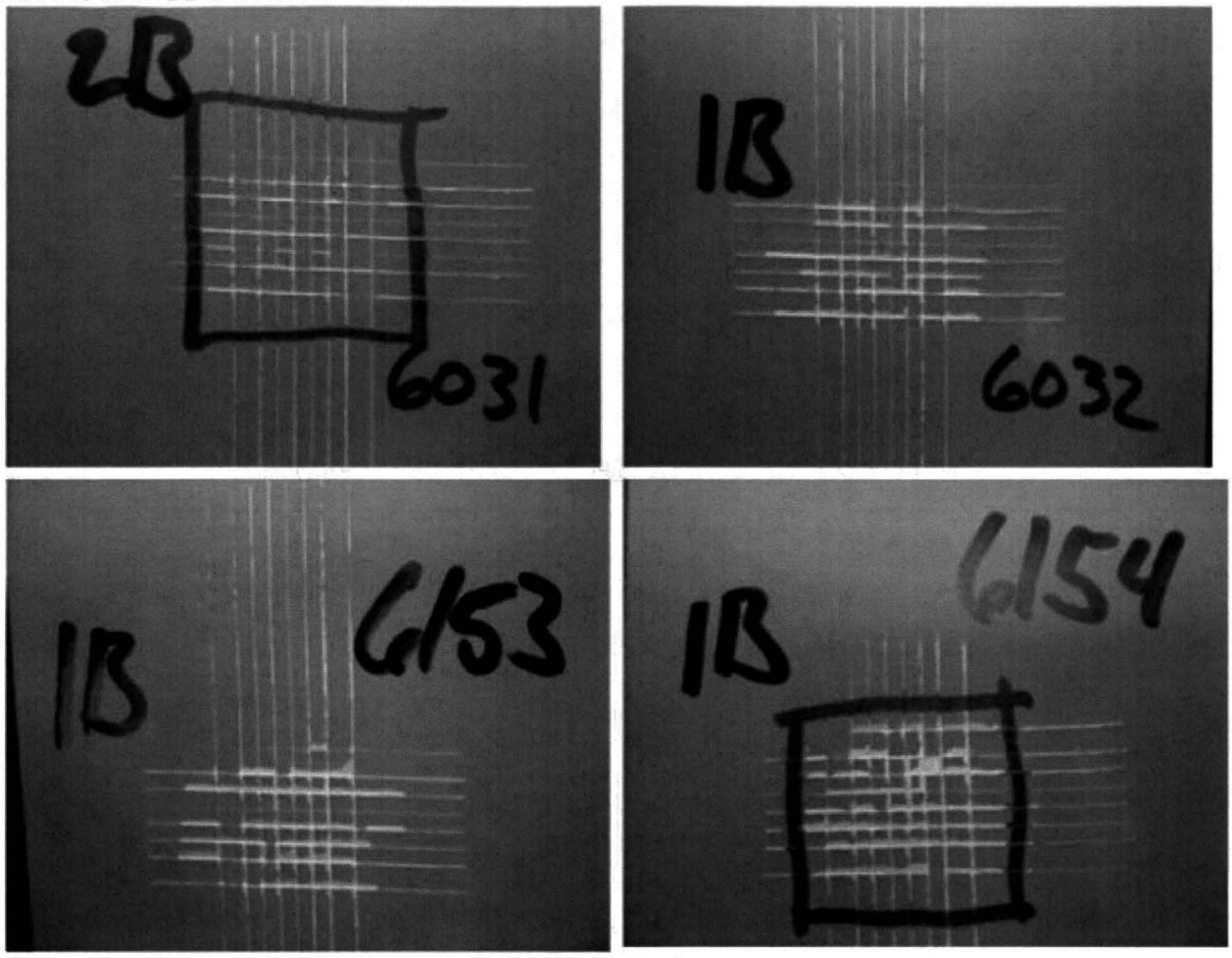

Figure 191 – SurTec 650; 6061-T6 (Top), 5052-H32 (Bottom)

SurTec 650C - PPG CA7233 - PPG CA9311

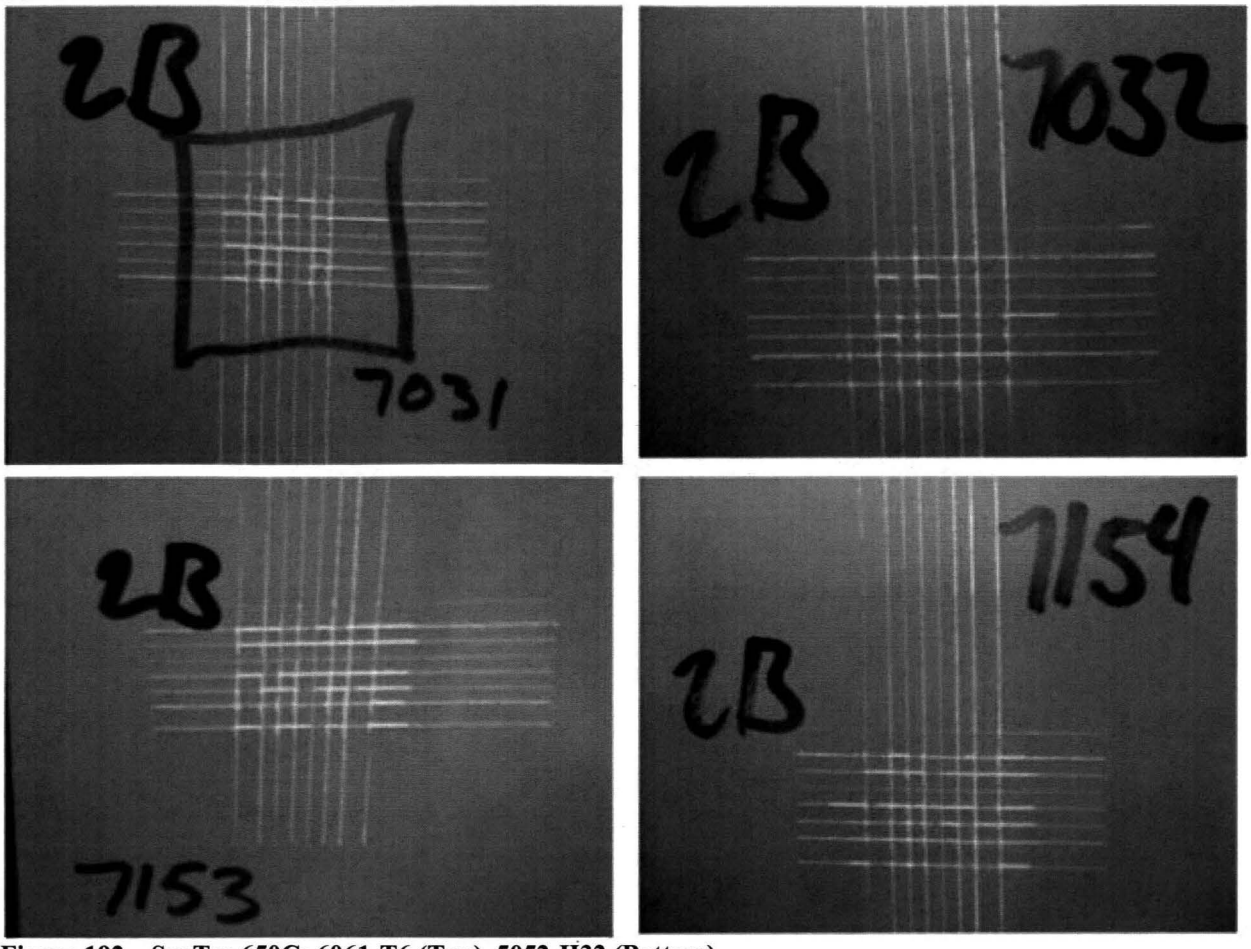

Figure 192 – SurTec 650C; 6061-T6 (Top), 5052-H32 (Bottom)

Alodine T 5900 RTU – Deft-44-GN-07A - PPG CA9311

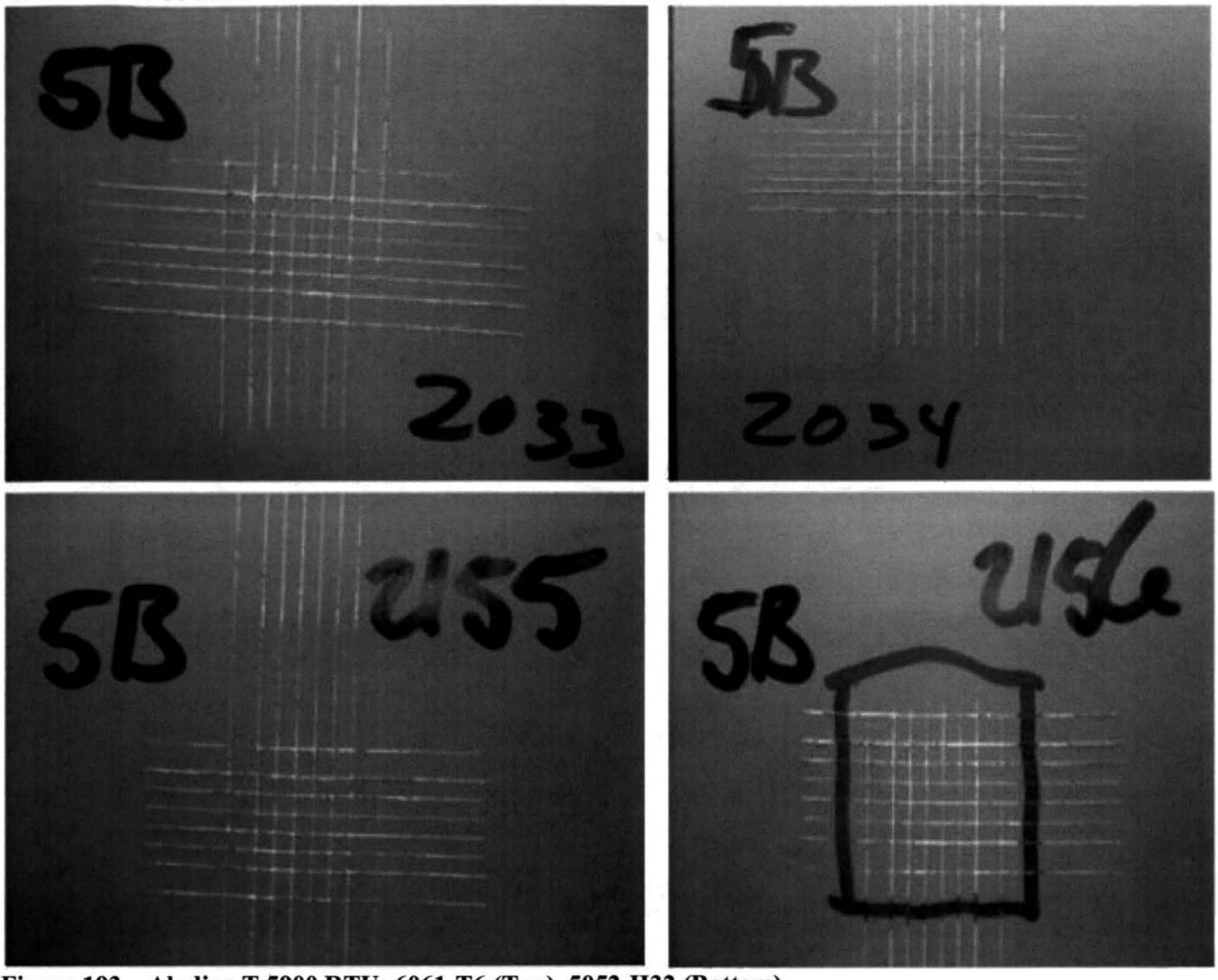

Figure 193 – Alodine T 5900 RTU; 6061-T6 (Top), 5052-H32 (Bottom)

Iridite NCP - Deft-44-GN-07A - PPG CA9311

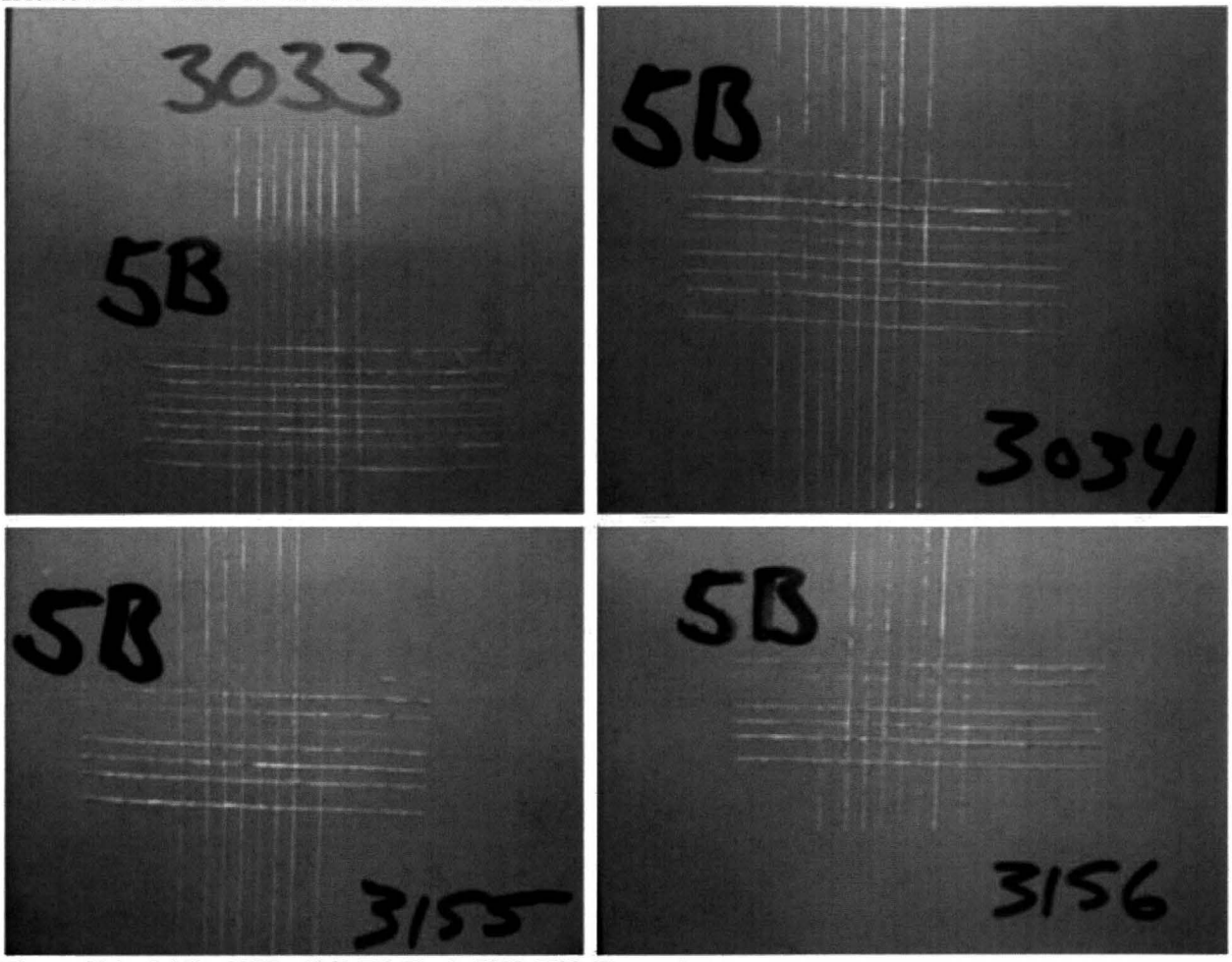

Figure 194 – Iridite NCP; 6061-T6 (Top), 5052-H32 (Bottom)

Metalast HF – Deft-44-GN-07A - PPG CA9311

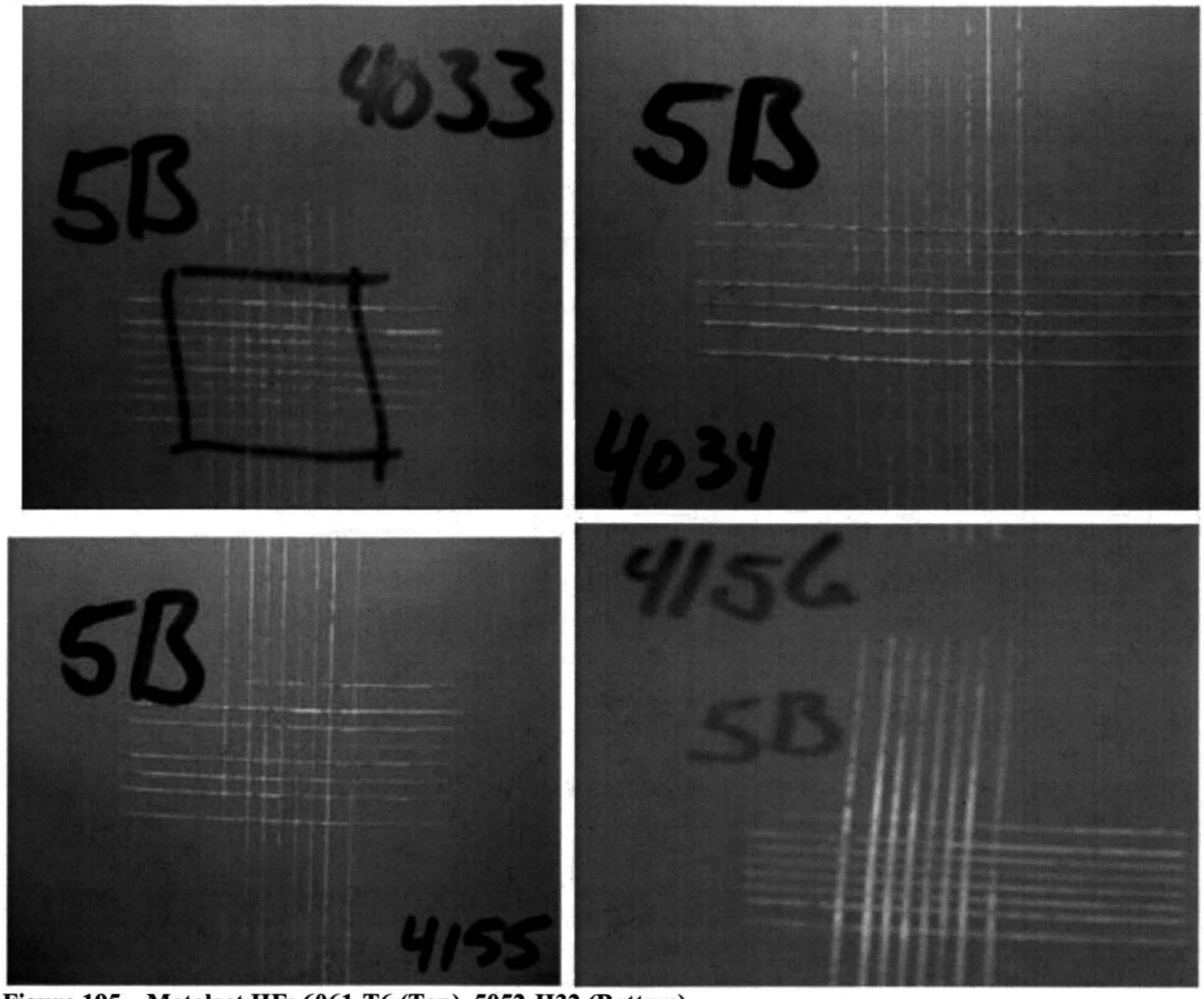

Figure 195 – Metalast HF; 6061-T6 (Top), 5052-H32 (Bottom)

Metalast HF-EPA – Deft-44-GN-07A - PPG CA9311

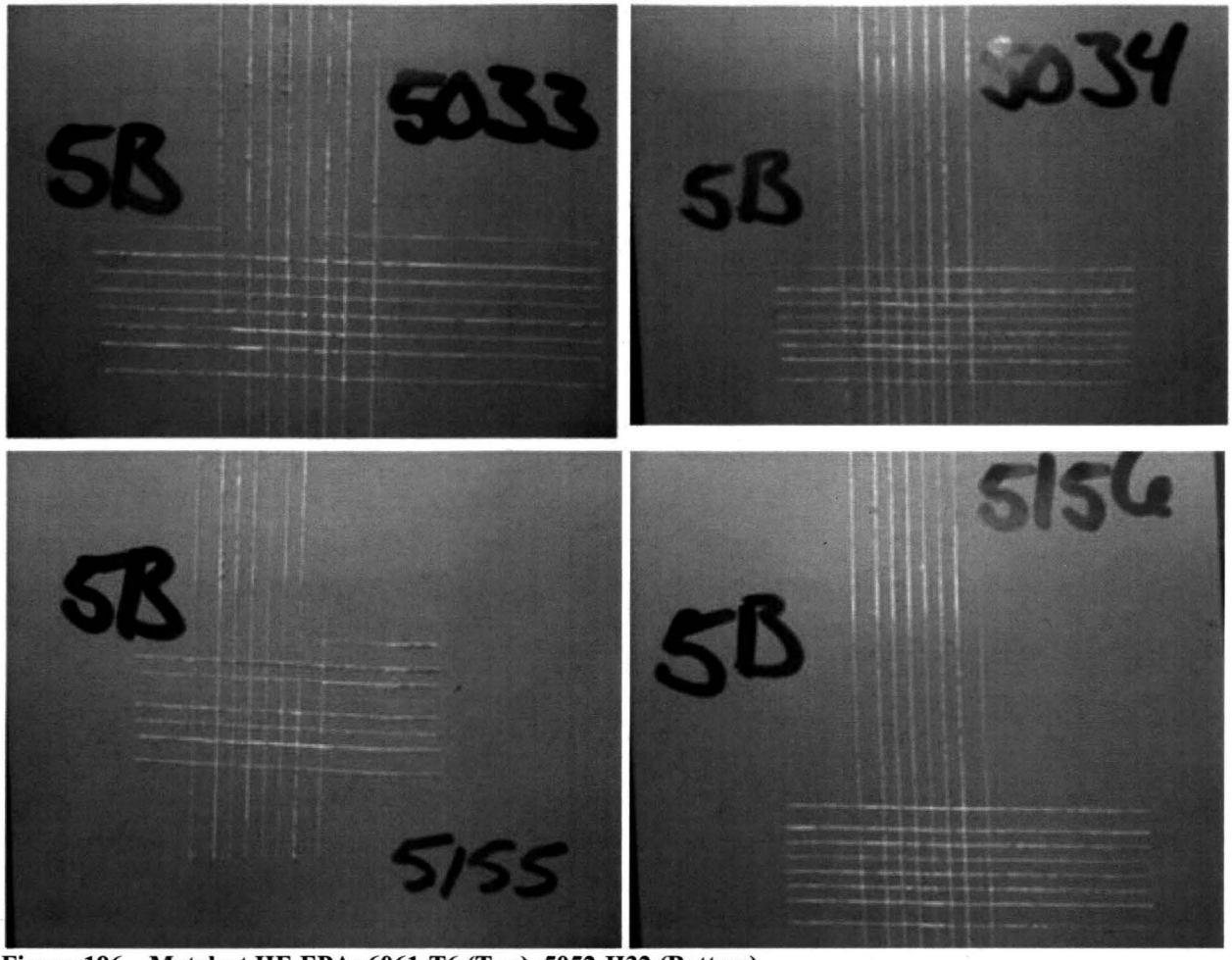

Figure 196 – Metalast HF-EPA; 6061-T6 (Top), 5052-H32 (Bottom)

SurTec 650 – Deft-44-GN-07A - PPG CA9311

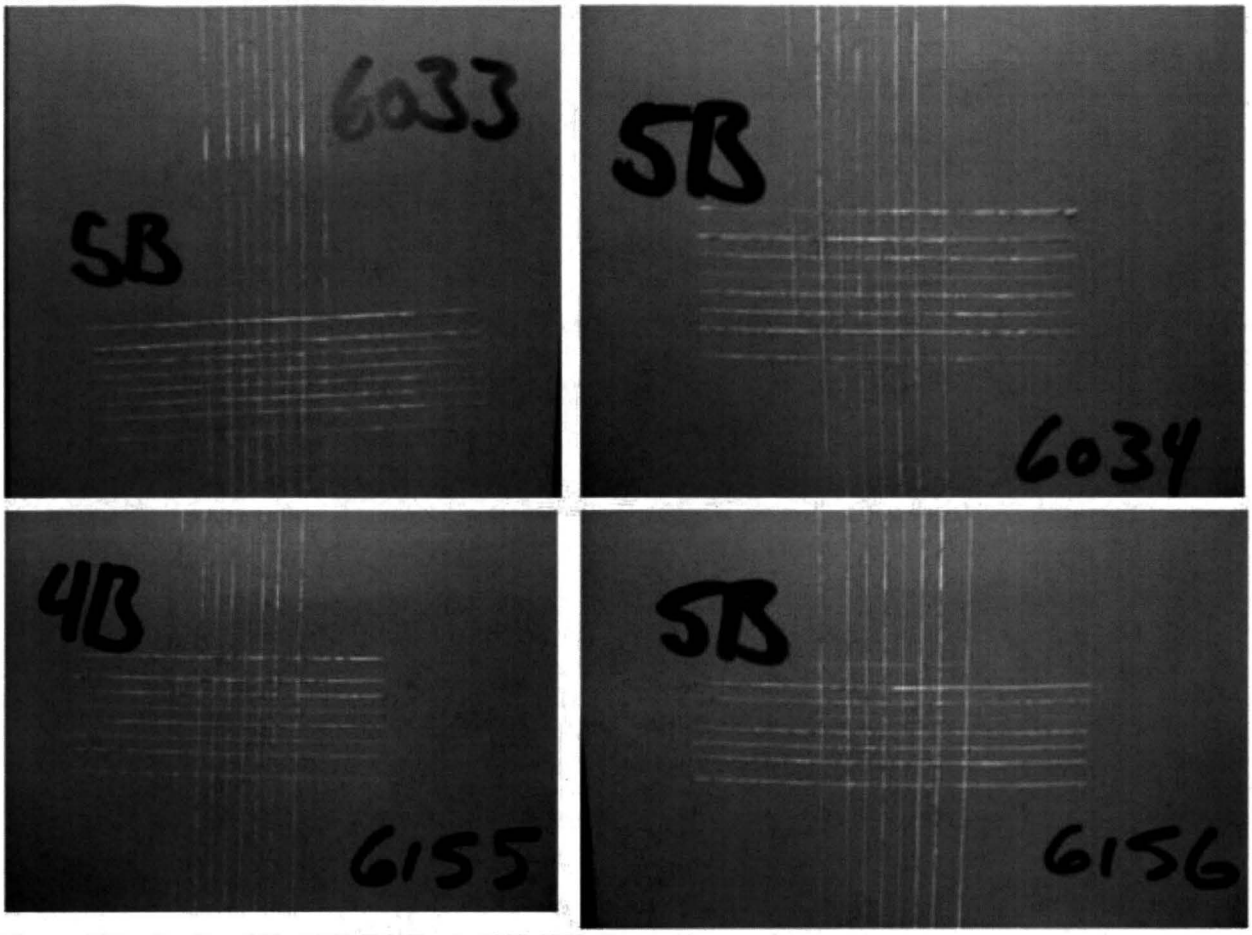

Figure 197 – SurTec 650; 6061-T6 (Top), 5052-H32 (Bottom)

SurTec 650C – Deft-44-GN-07A - PPG CA9311

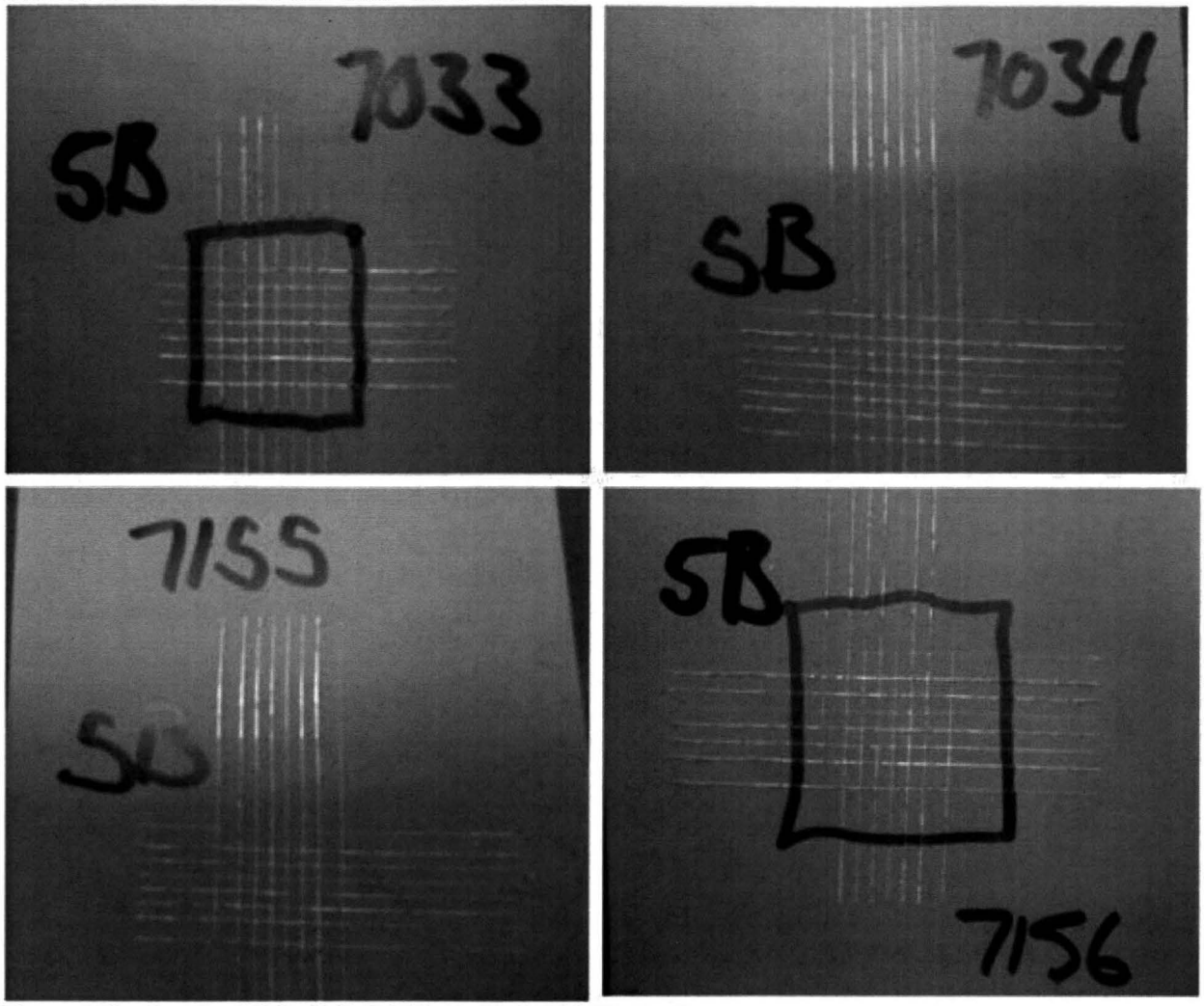

Figure 198 – SurTec 650C; 6061-T6 (Top), 5052-H32 (Bottom)

Appendix H –
Panel Photographs Wet Tape Adhesion, 24 Hour Immersion

Alodine T 5900 RTU - PPG CA7233

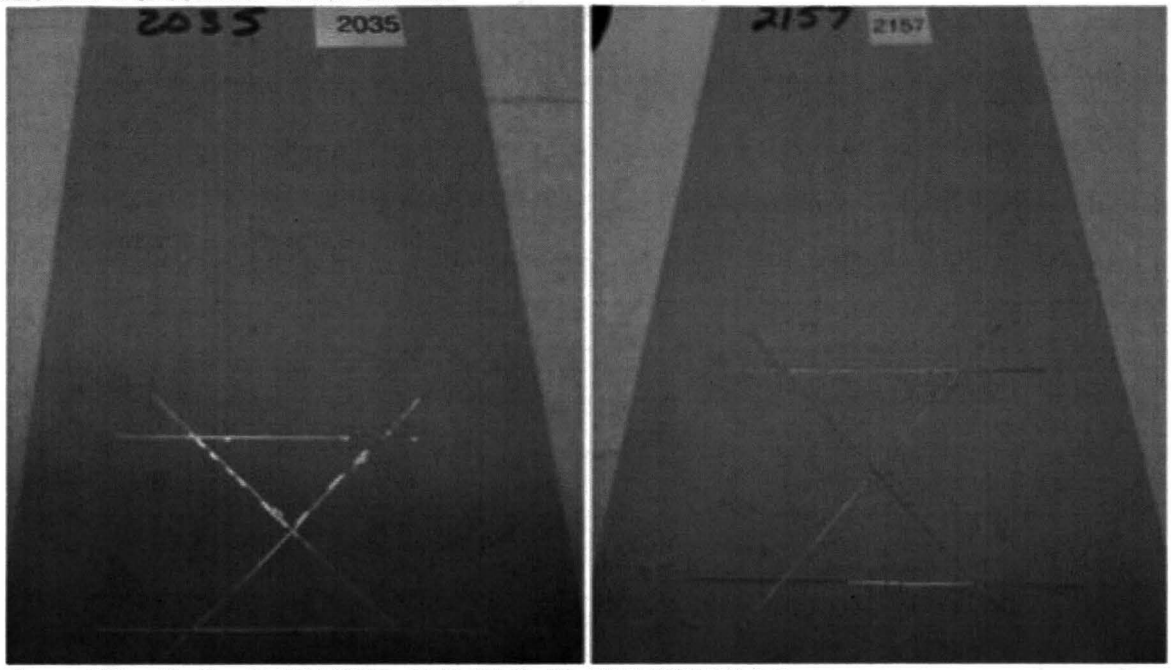

Figure 199 – Alodine T 5900 RTU; 6061-T6 (Left), 5052-H32 (Right)

Iridite NCP - PPG CA7233

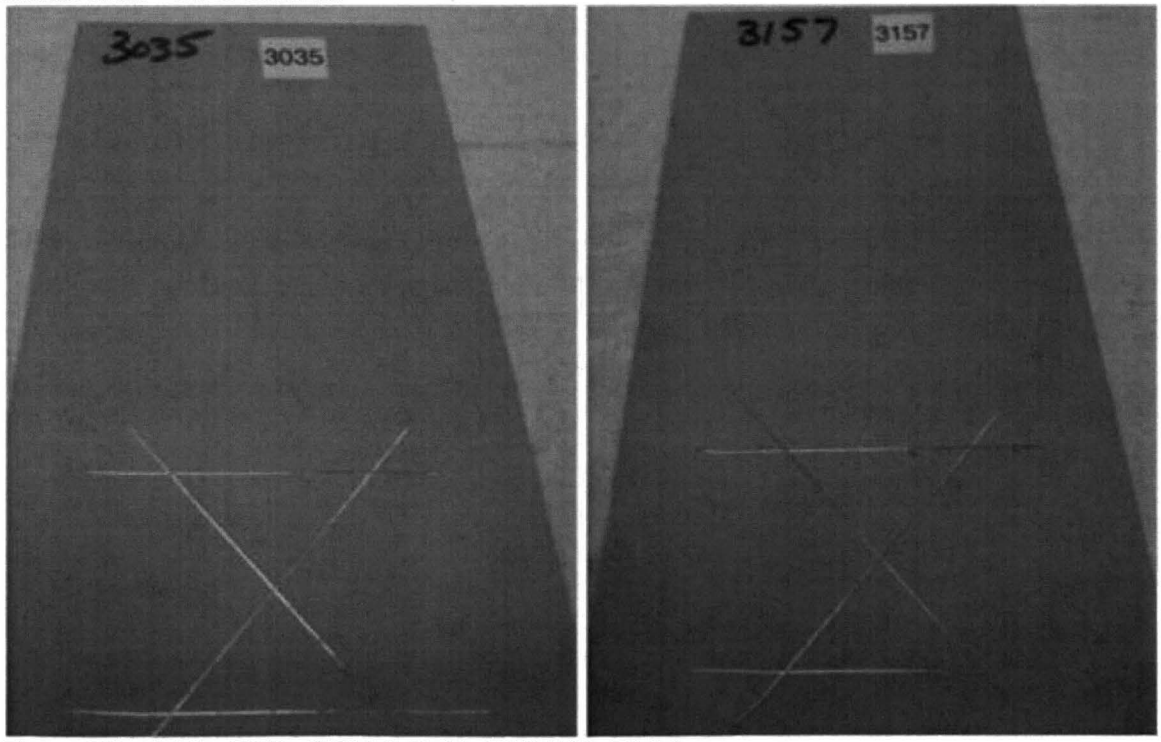

Figure 200 – Iridite NCP; 6061-T6 (Left), 5052-H32 (Right)

Metalast HF - PPG CA7233

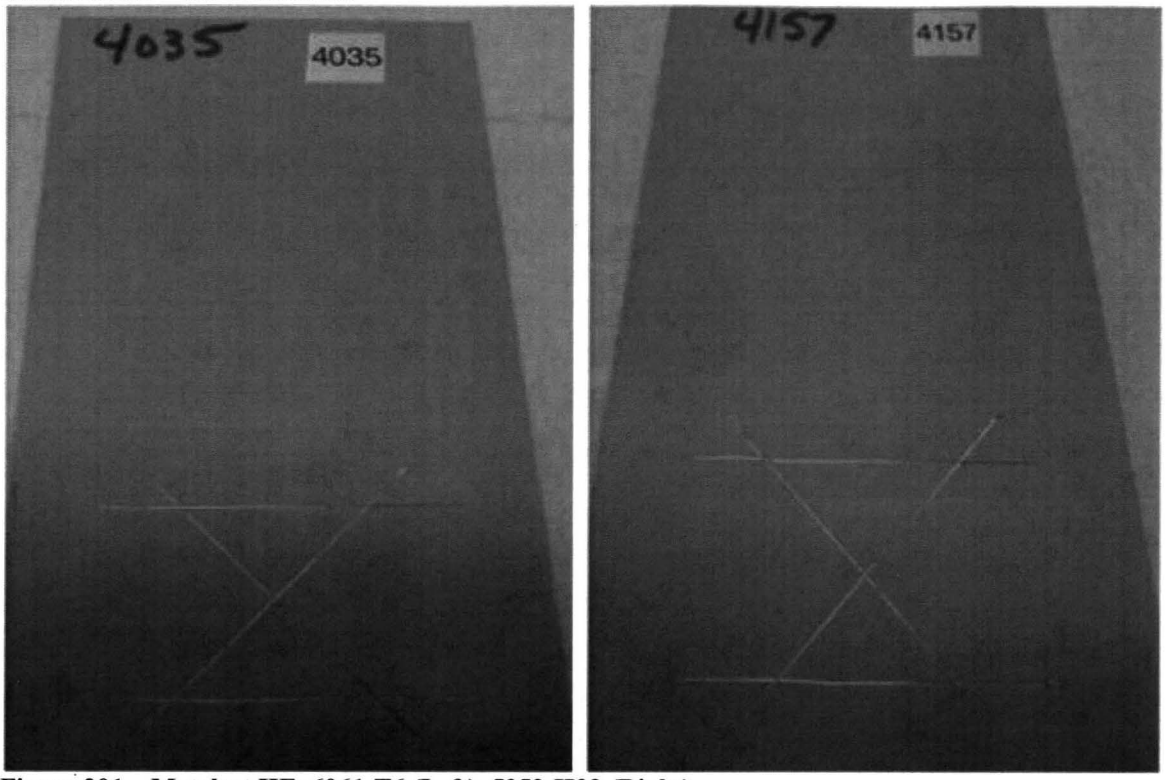

Figure 201 – Metalast HF; 6061-T6 (Left), 5052-H32 (Right)

Metalast HF-EPA - PPG CA7233

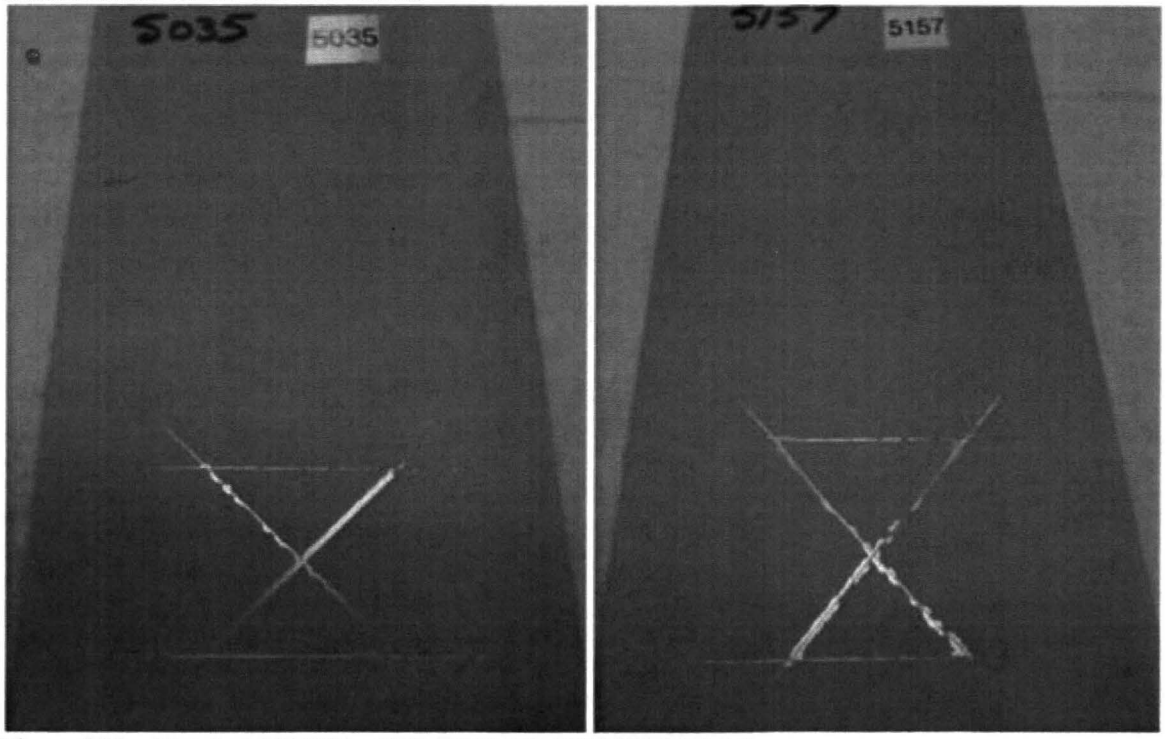

Figure 202 – Metalast HF-EPA; 6061-T6 (Left), 5052-H32 (Right)

SurTec 650 - PPG CA7233

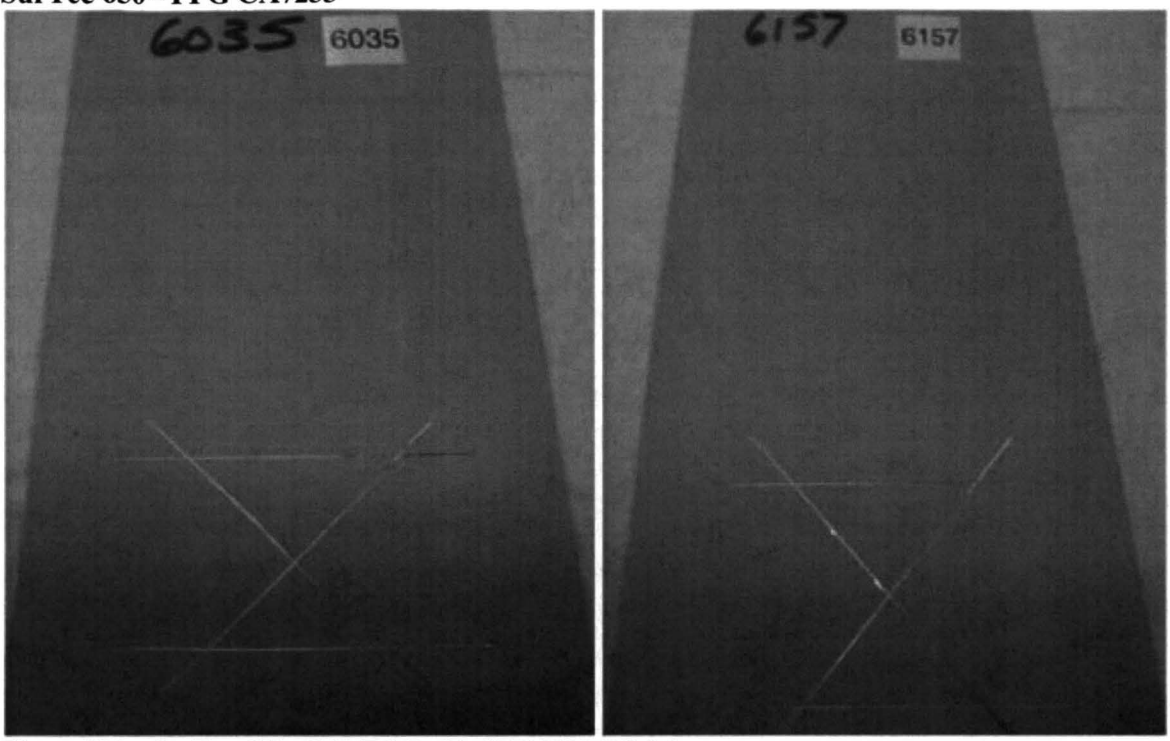

Figure 203 – SurTec 650; 6061-T6 (Left), 5052-H32 (Right)

SurTec 650C - PPG CA7233

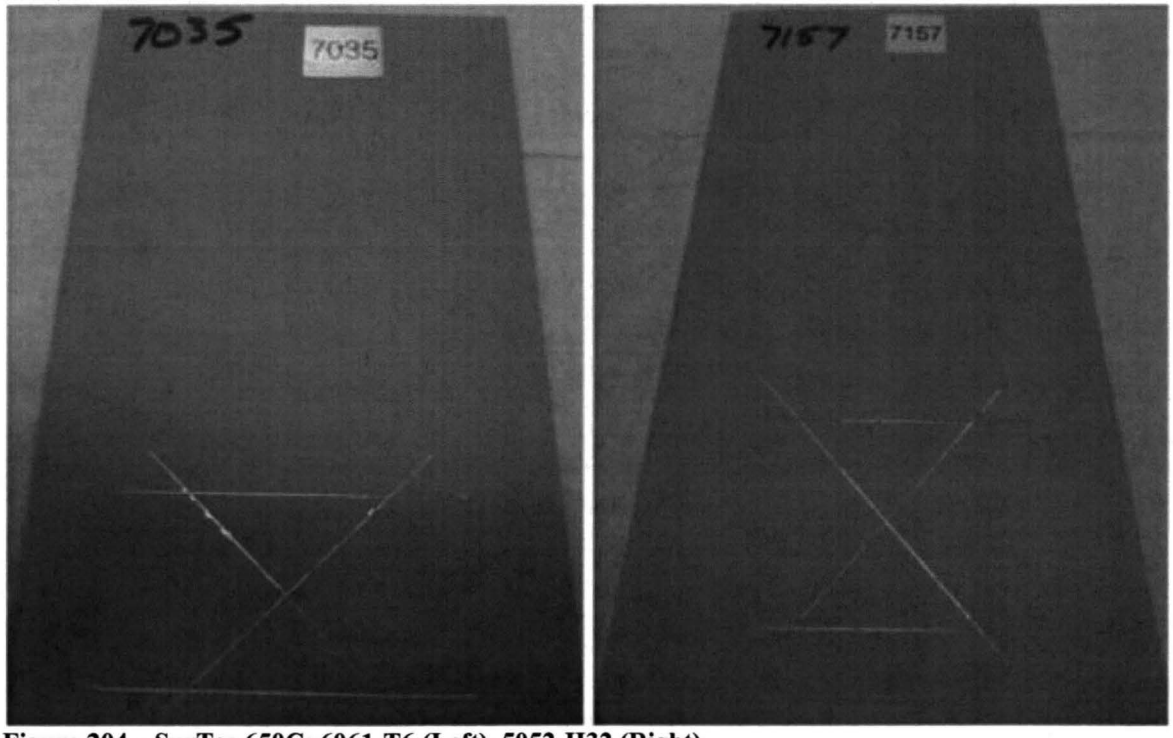

Figure 204 – SurTec 650C; 6061-T6 (Left), 5052-H32 (Right)

Alodine T 5900 RTU – Deft 44-GN-07A

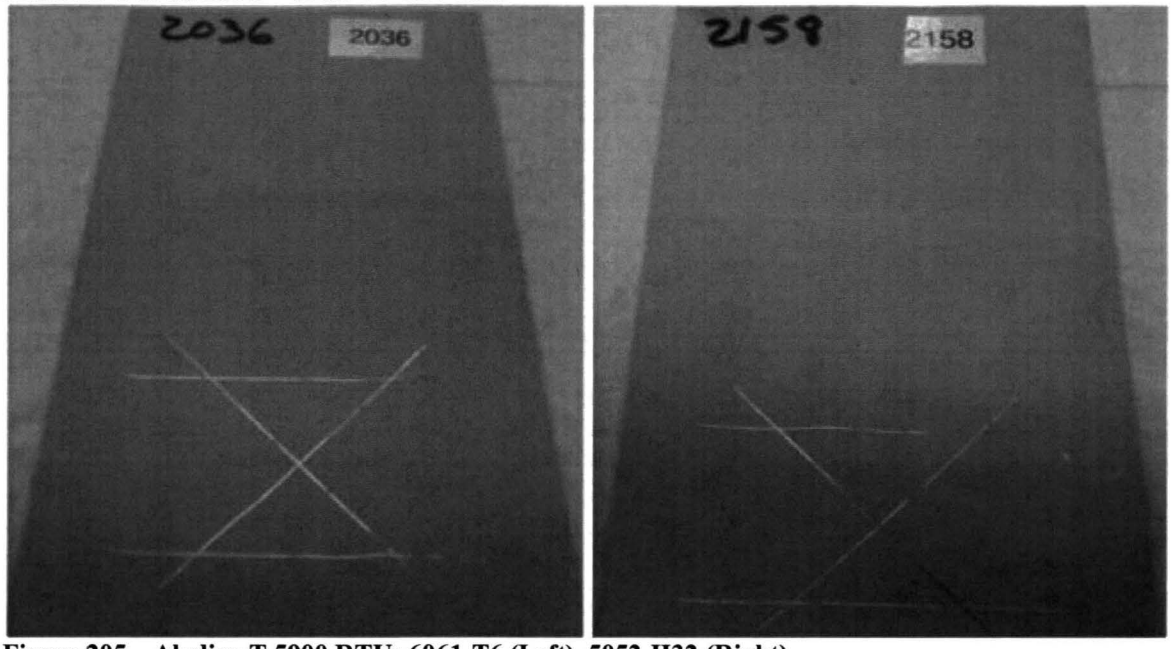

Figure 205 – Alodine T 5900 RTU; 6061-T6 (Left), 5052-H32 (Right)

Iridite NCP - Deft 44-GN-07A

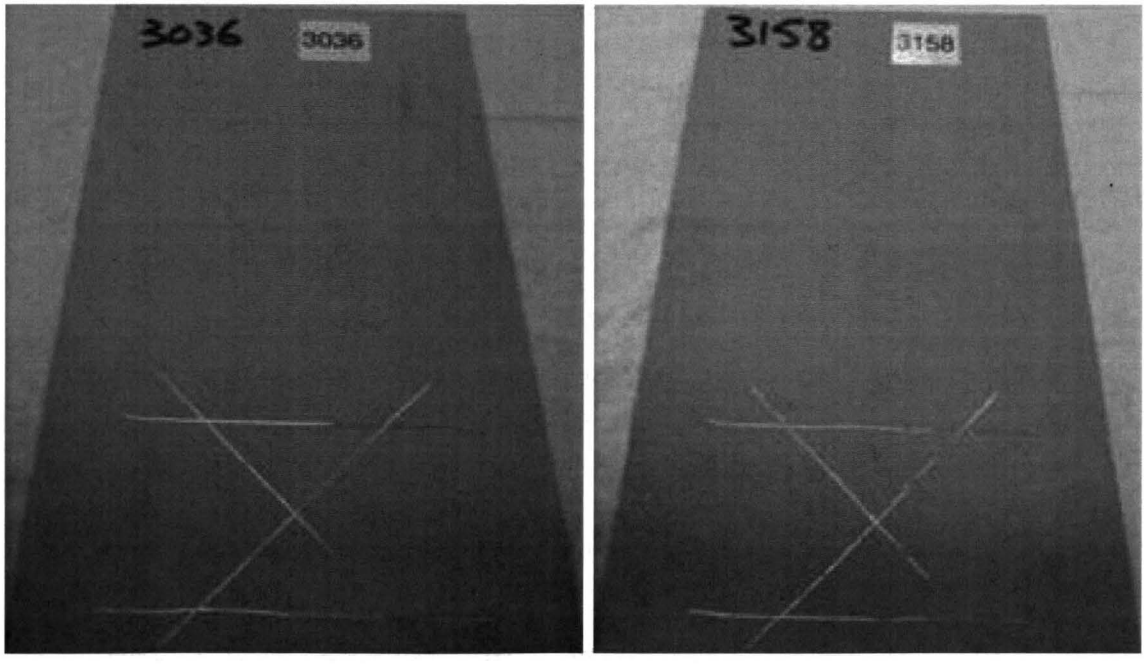

Figure 206 – Iridite NCP; 6061-T6 (Left), 5052-H32 (Right)

Metalast HF - Deft 44-GN-07A

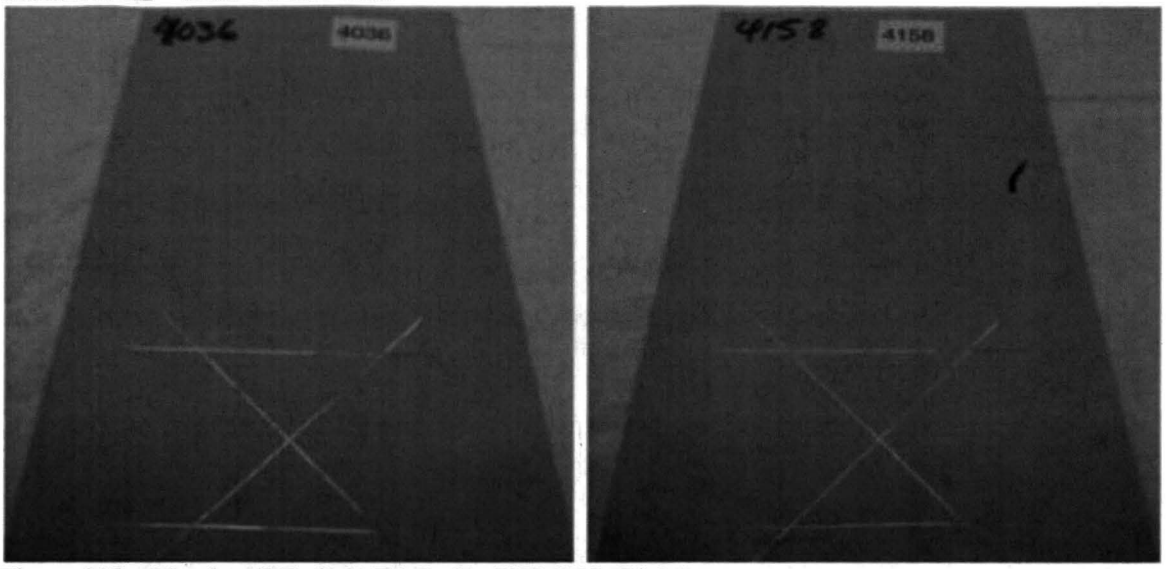

Figure 207 – Metalast HF; 6061-T6 (Left), 5052-H32 (Right)

Metalast HF-EPA - Deft 44-GN-07A

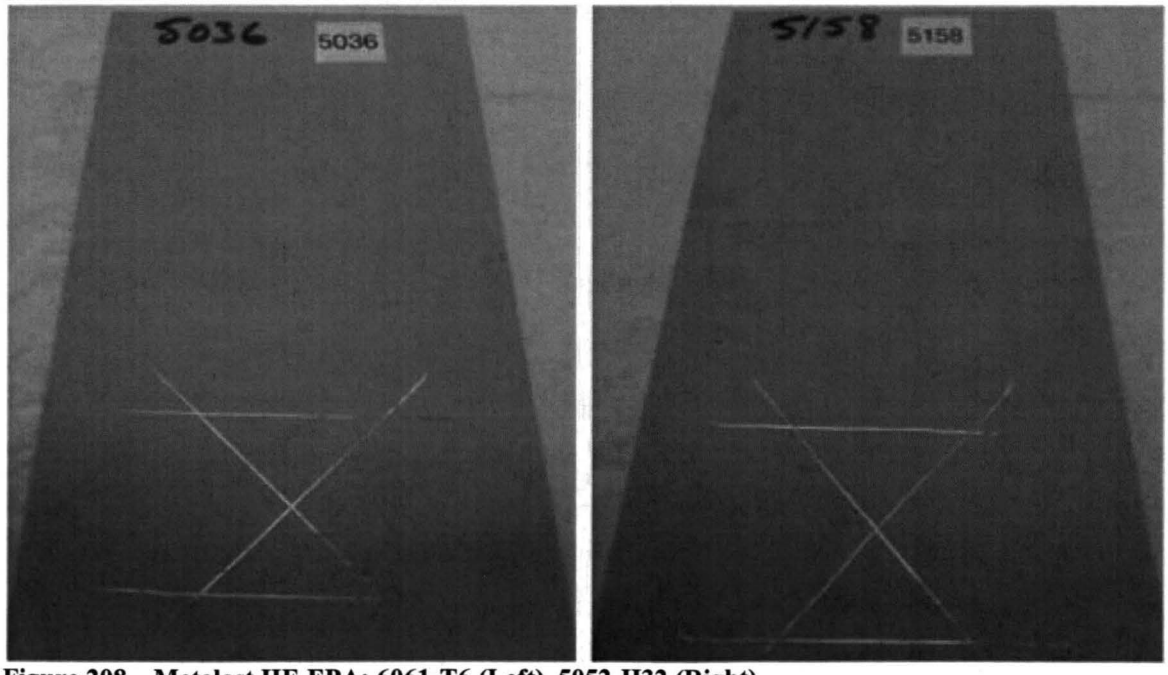

Figure 208 – Metalast HF-EPA; 6061-T6 (Left), 5052-H32 (Right)

SurTec 650 - Deft 44-GN-07A

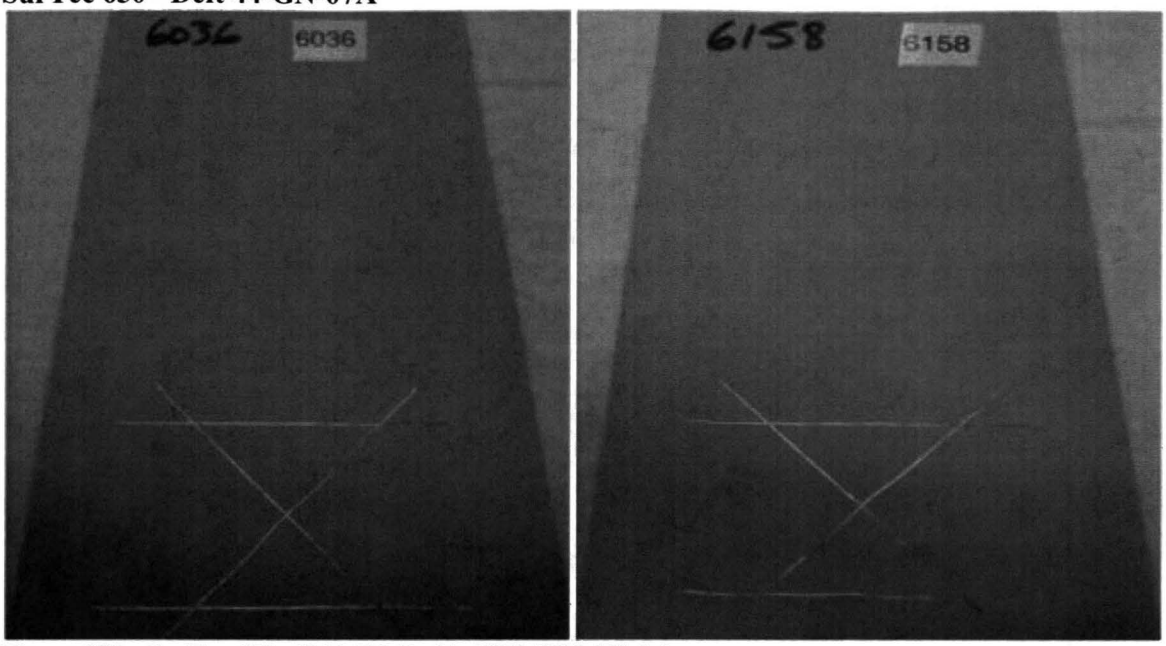

Figure 209 - SurTec 650; 6061-T6 (Left), 5052-H32 (Right)

SurTec 650C - Deft 44-GN-07A

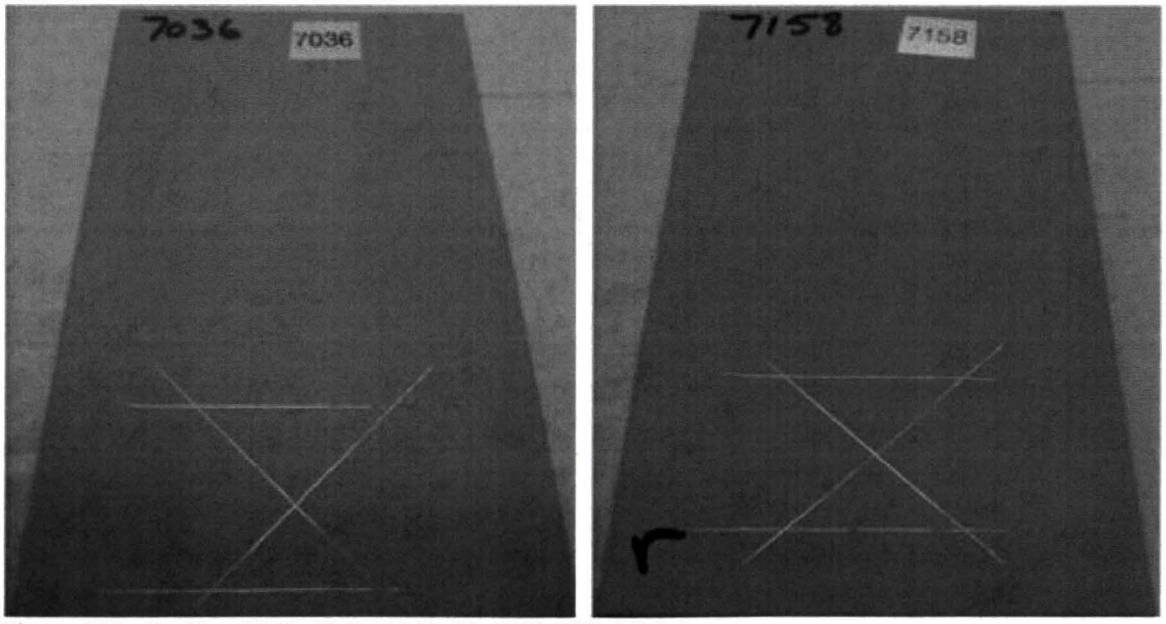

Figure 210 - SurTec 650C; 6061-T6 (Left), 5052-H32 (Right)

Appendix I –
Panel Photographs Wet Tape Adhesion, 96 Hour Immersion @ 120°F

Alodine T 5900 RTU – PPG CA7233

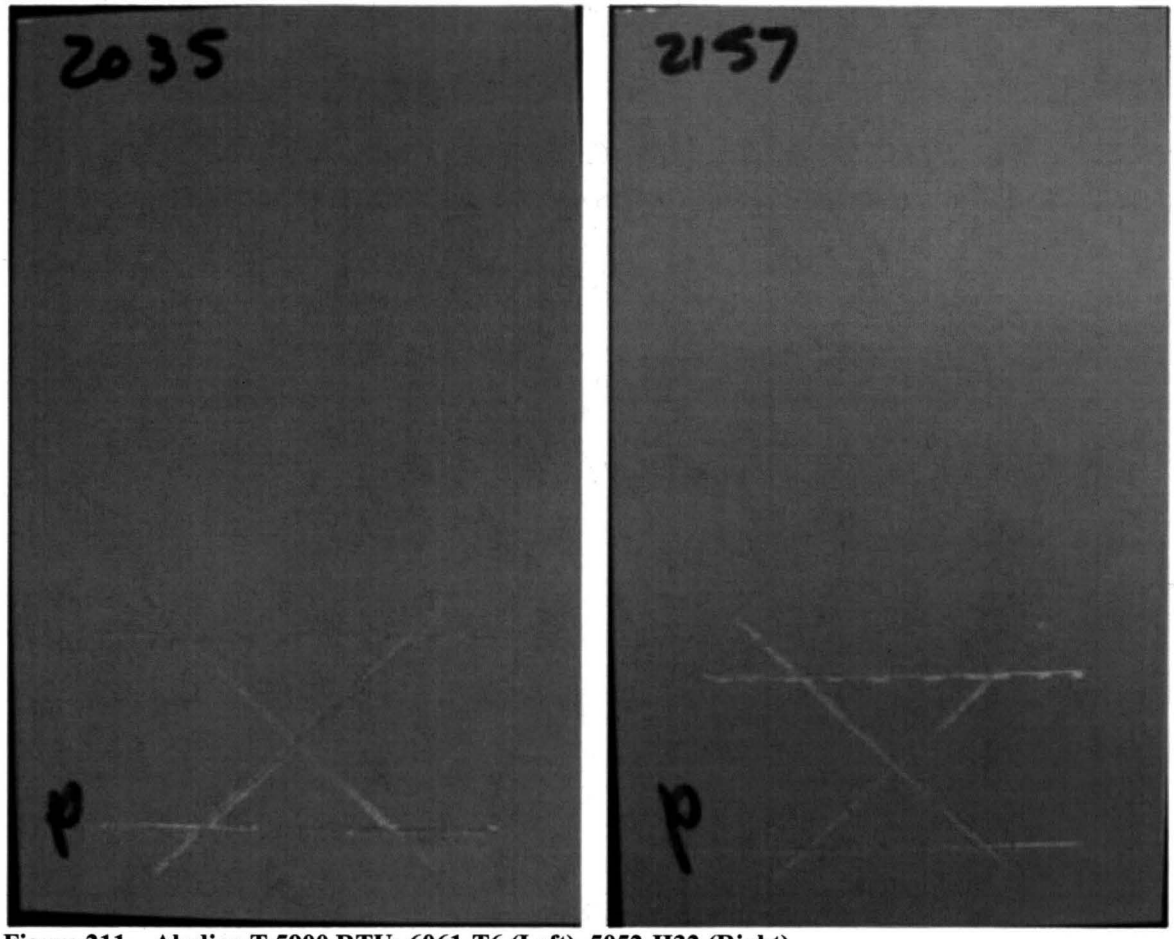

Figure 211 – Alodine T 5900 RTU; 6061-T6 (Left), 5052-H32 (Right)

Iridite NCP - PPG CA7233

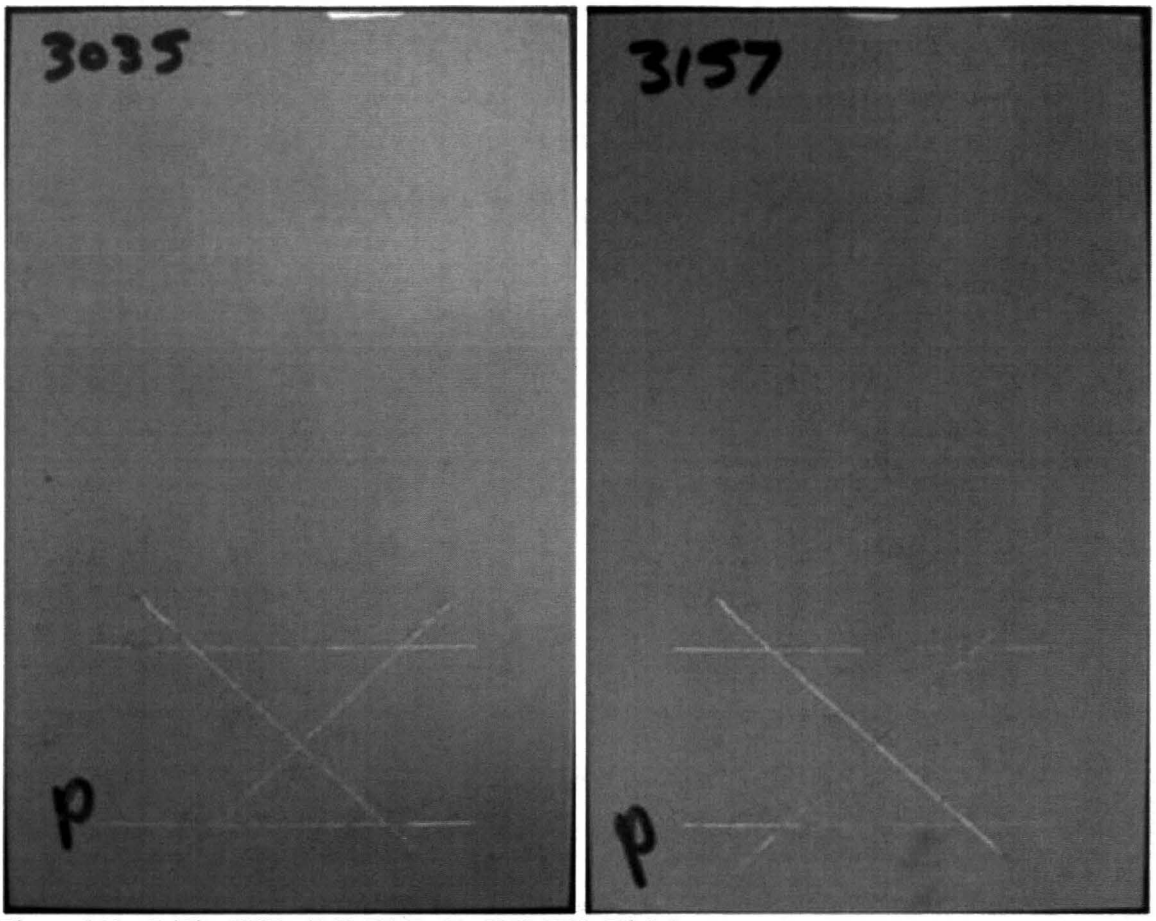

Figure 212 – Iridite NCP; 6061-T6 (Left), 5052-H32 (Right)

Metalast HF - PPG CA7233

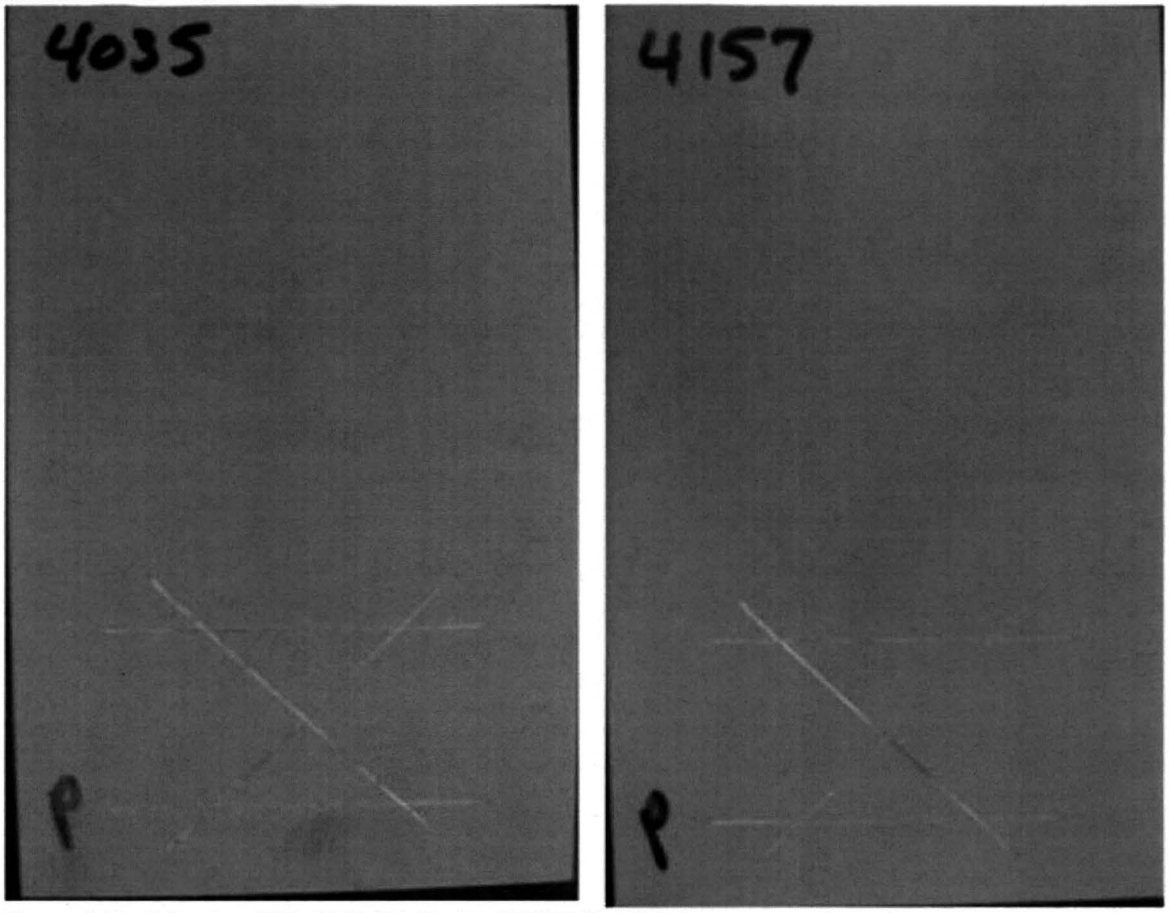

Figure 213 – Metalast HF; 6061-T6 (Left), 5052-H32 (Right)

Metalast HF-EPA - PPG CA7233

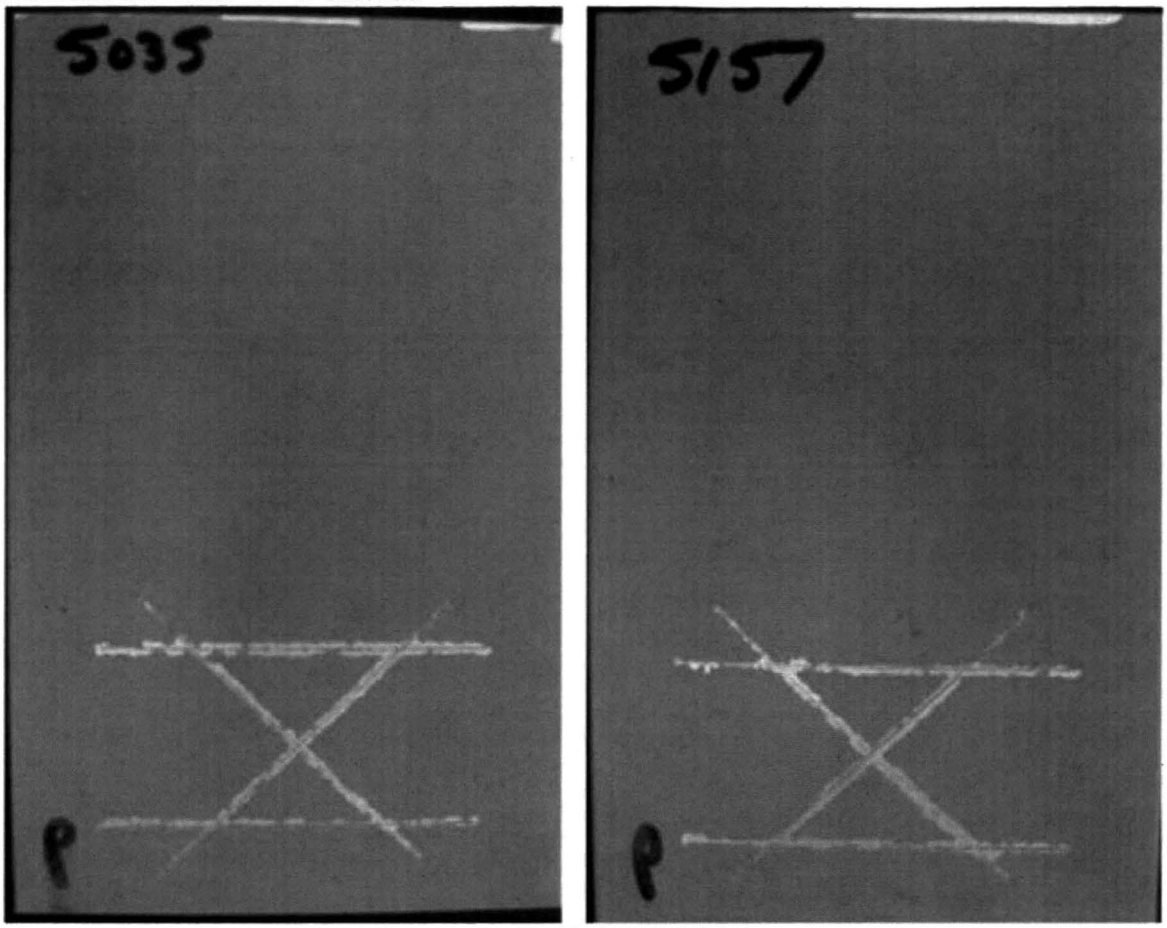

Figure 214 – Metalast HF-EPA; 6061-T6 (Left), 5052-H32 (Right)

SurTec 650 - PPG CA7233

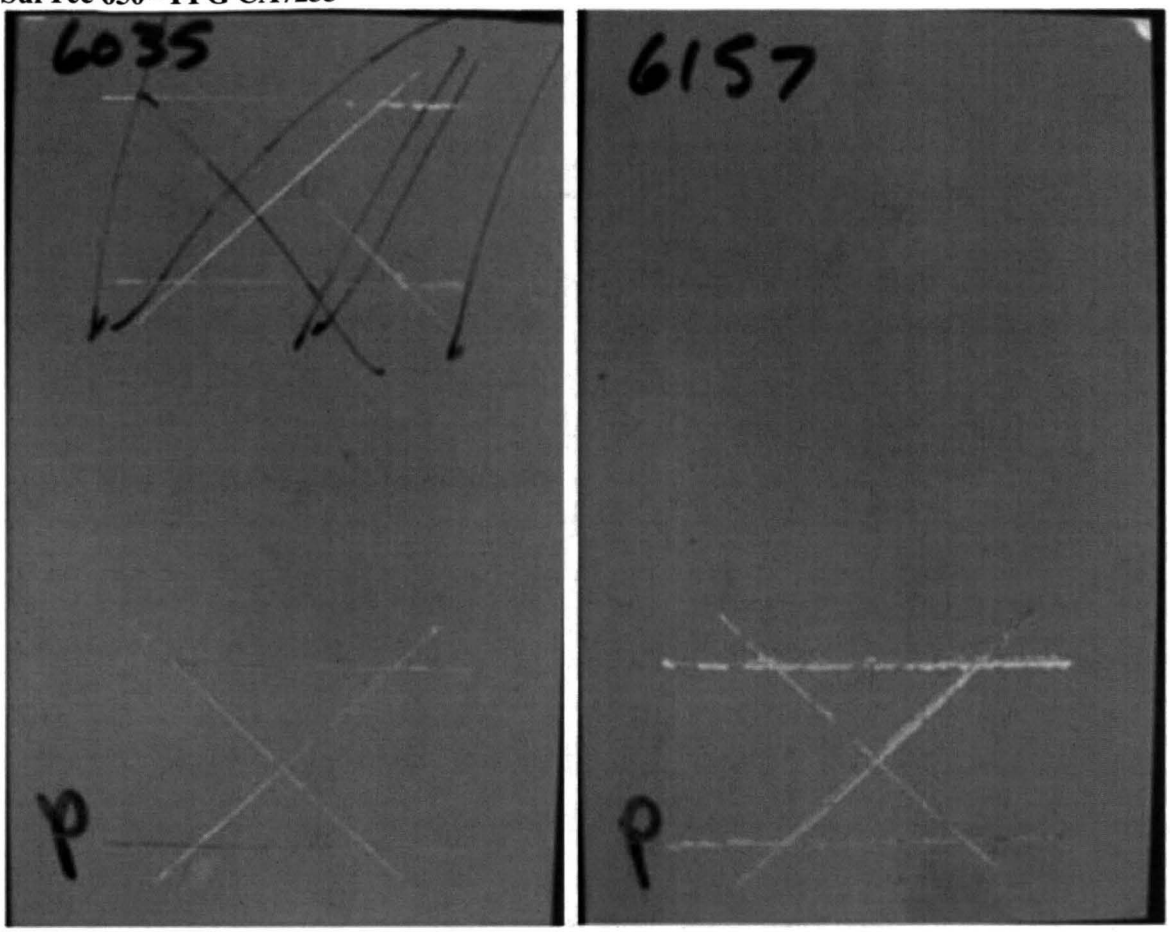

Figure 215 – SurTec 650; 6061-T6 (Left), 5052-H32 (Right)

SurTec 650C - PPG CA7233

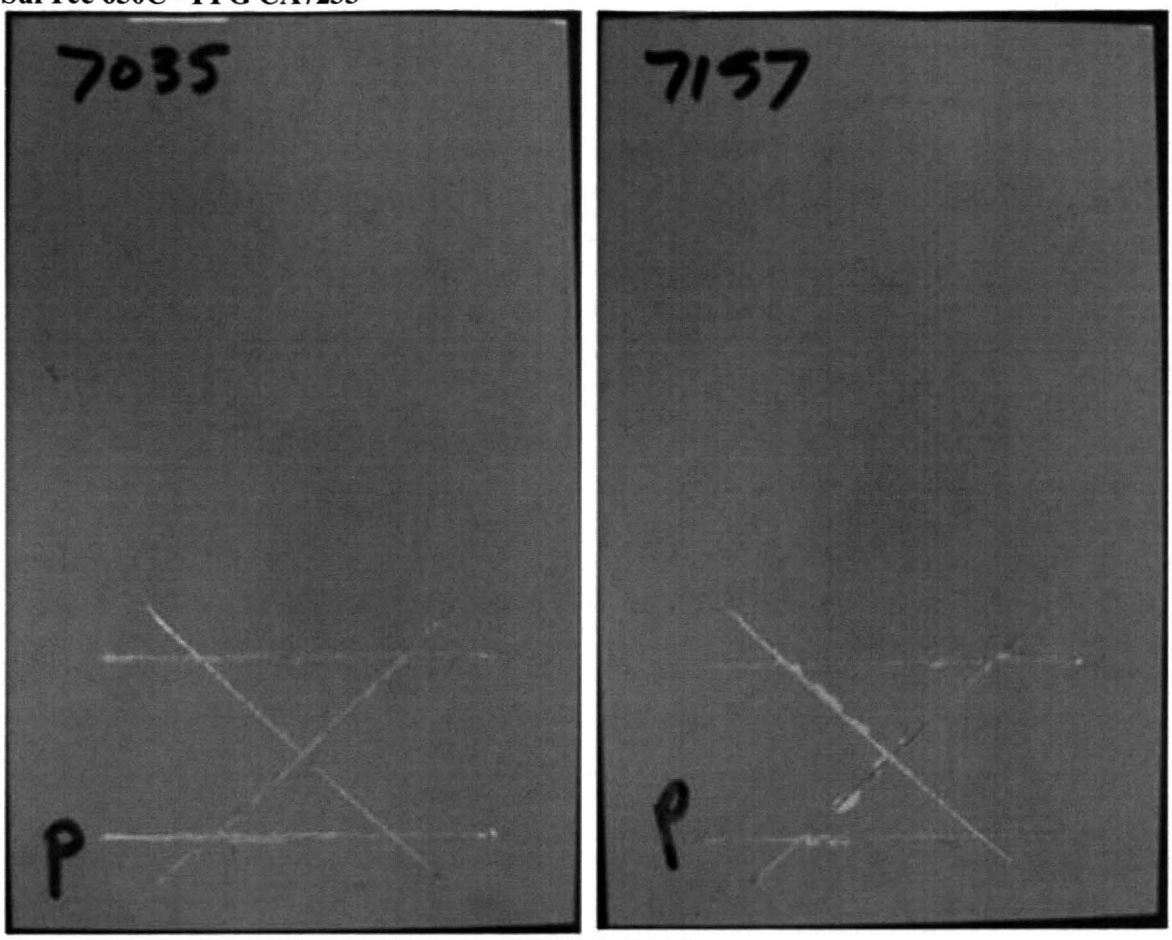

Figure 216 – SurTec 650C; 6061-T6 (Left), 5052-H32 (Right)

Alodine T 5900 RTU – Deft 44-GN-07A

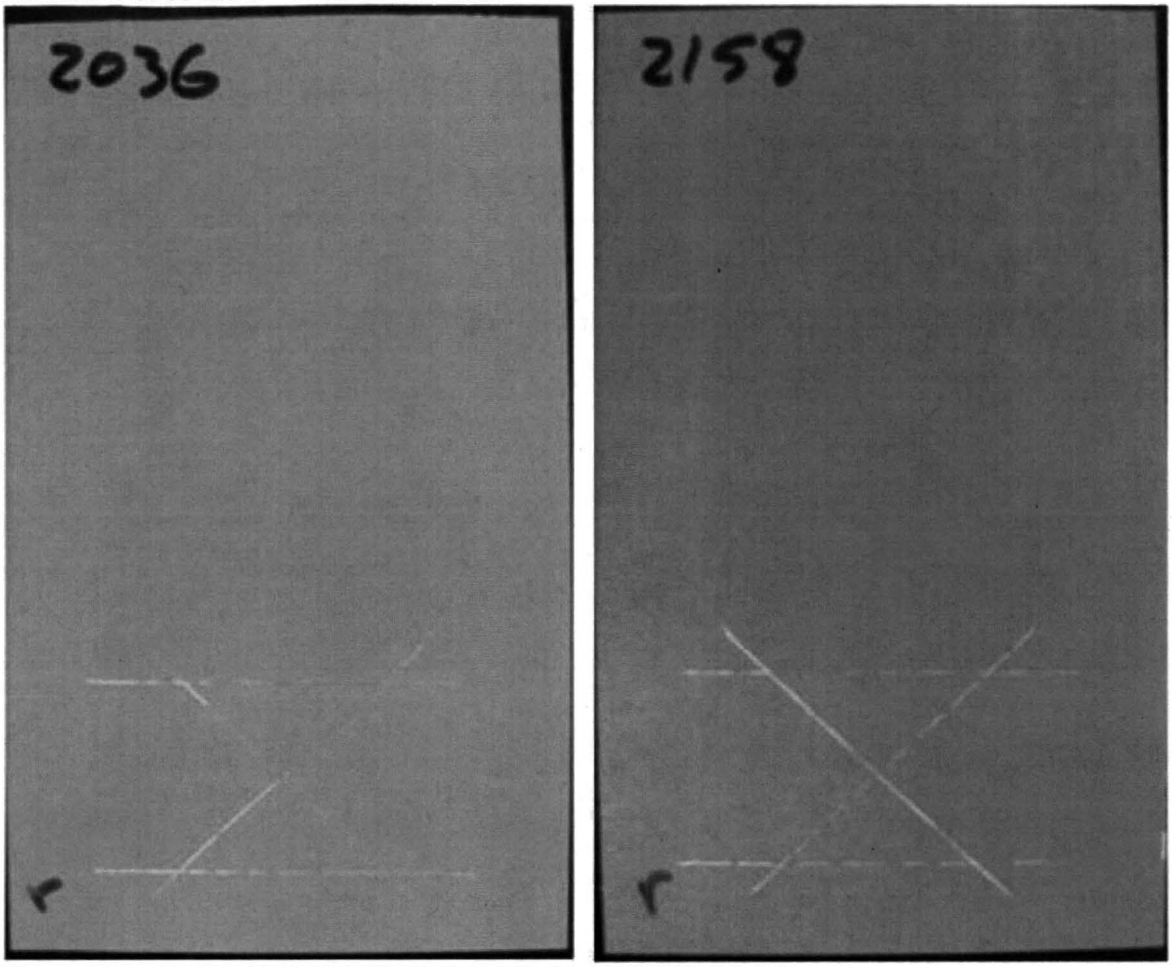

Figure 217 – Alodine T 5900 RTU; 6061-T6 (Left), 5052-H32 (Right)

Iridite NCP - Deft 44-GN-07A

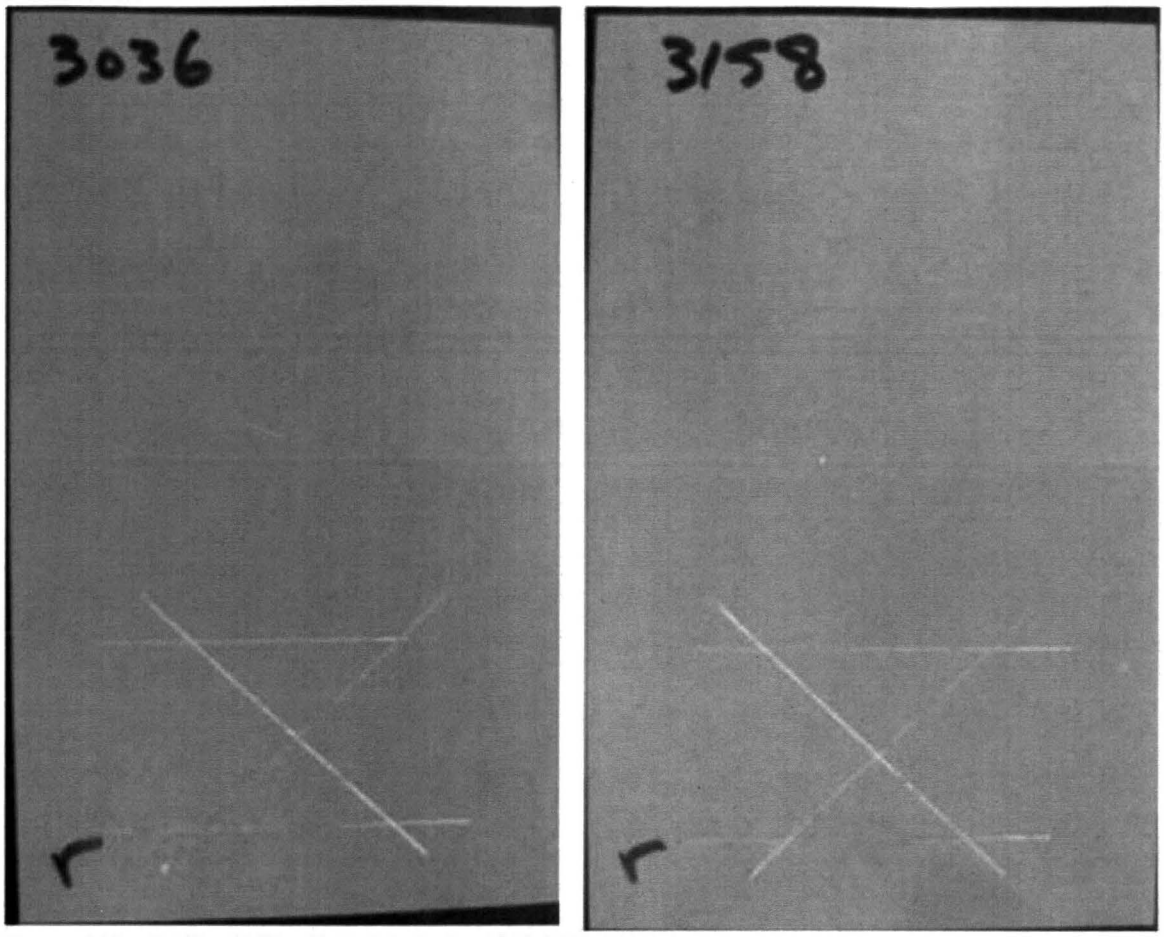

Figure 218 – Iridite NCP; 6061-T6 (Left), 5052-H32 (Right)

Metalast HF - Deft 44-GN-07A

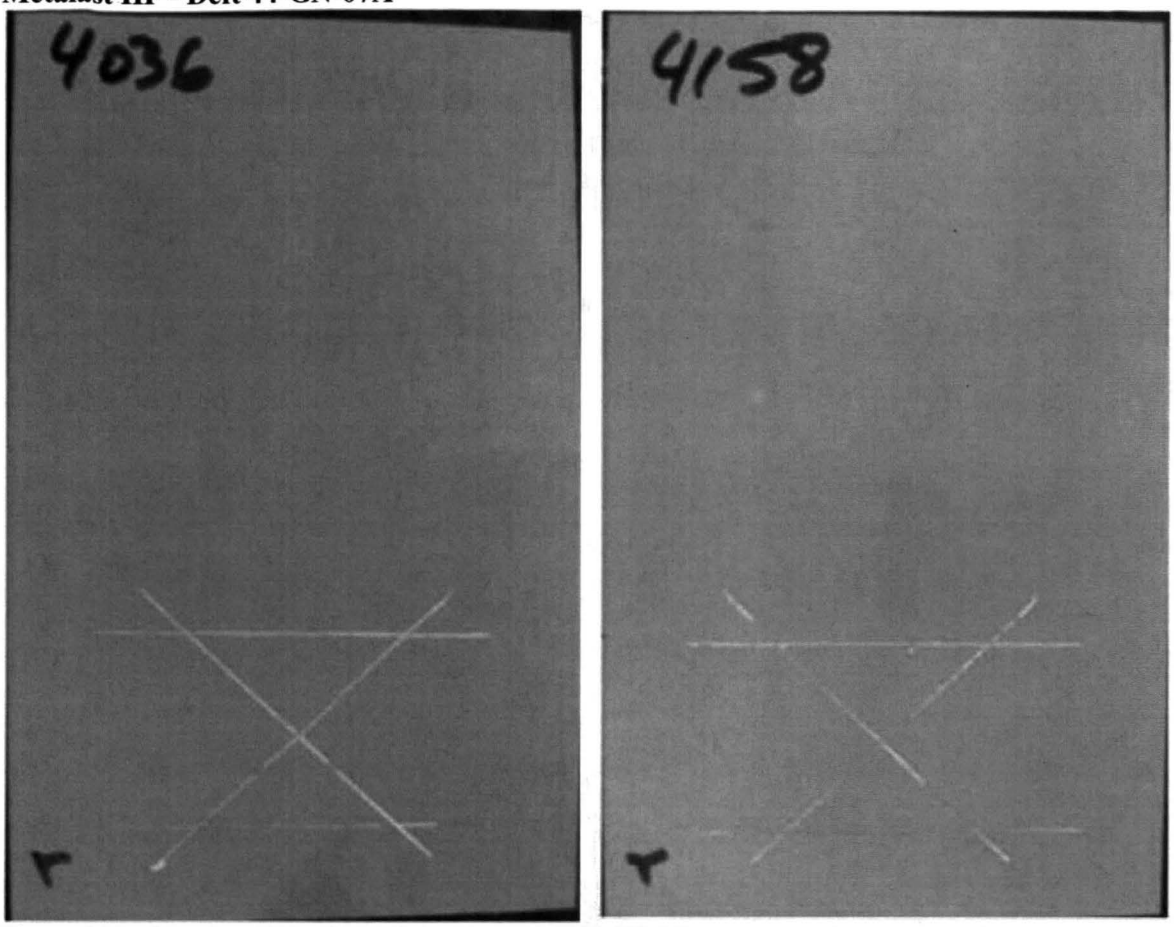

Figure 219 – Metalast HF; 6061-T6 (Left), 5052-H32 (Right)

Metalast HF-EPA - Deft 44-GN-07A

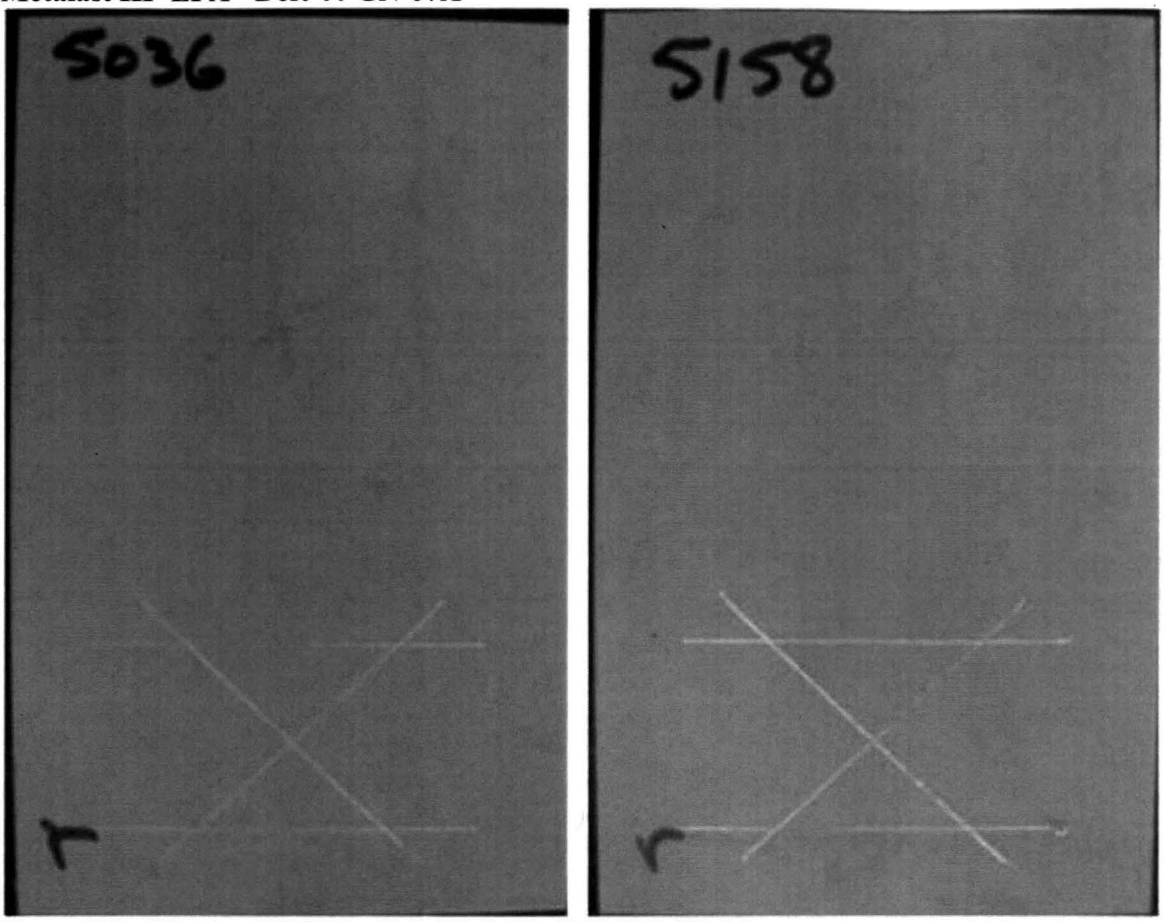

Figure 220 – Metalast HF-EPA; 6061-T6 (Left), 5052-H32 (Right)

SurTec 650 - Deft 44-GN-07A

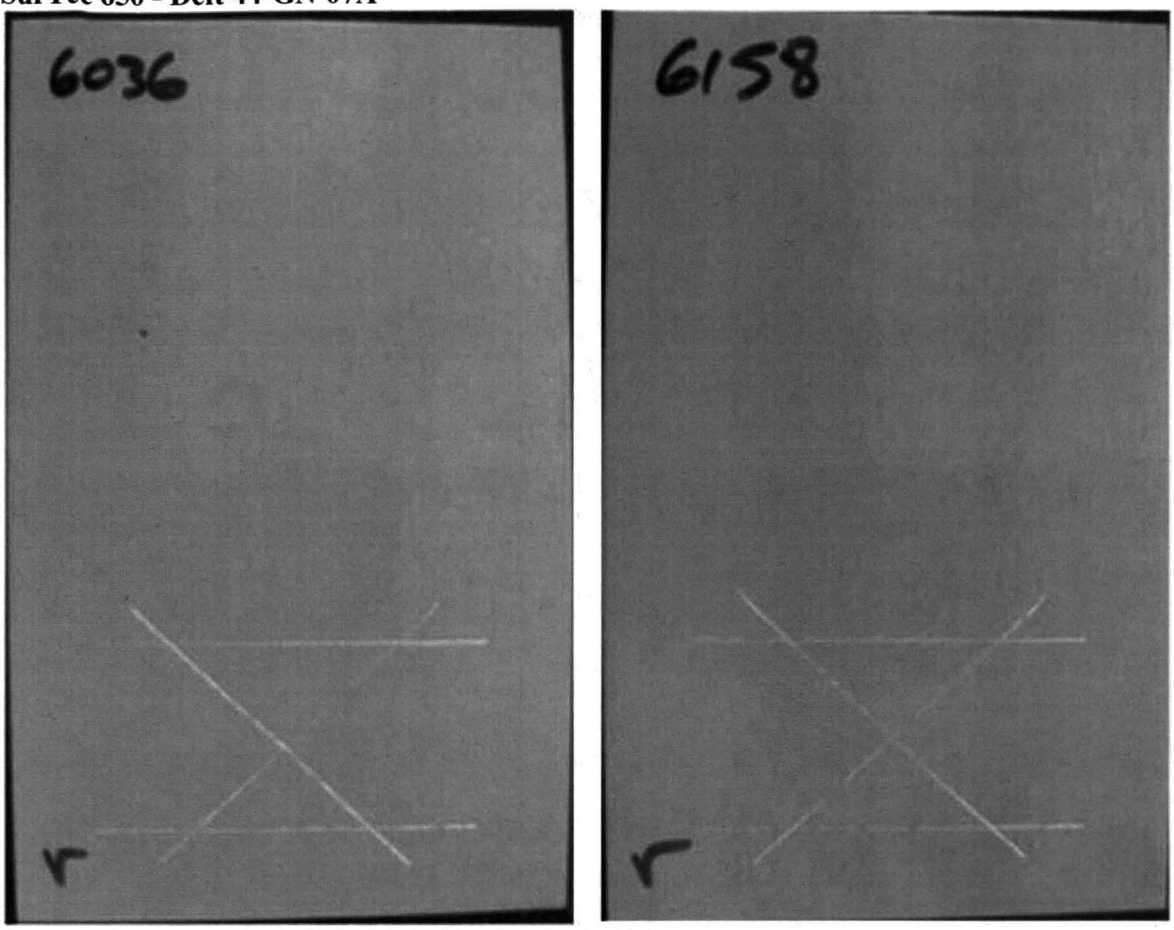

Figure 221 – SurTec 650; 6061-T6 (Left), 5052-H32 (Right)

SurTec 650C - Deft 44-GN-07A

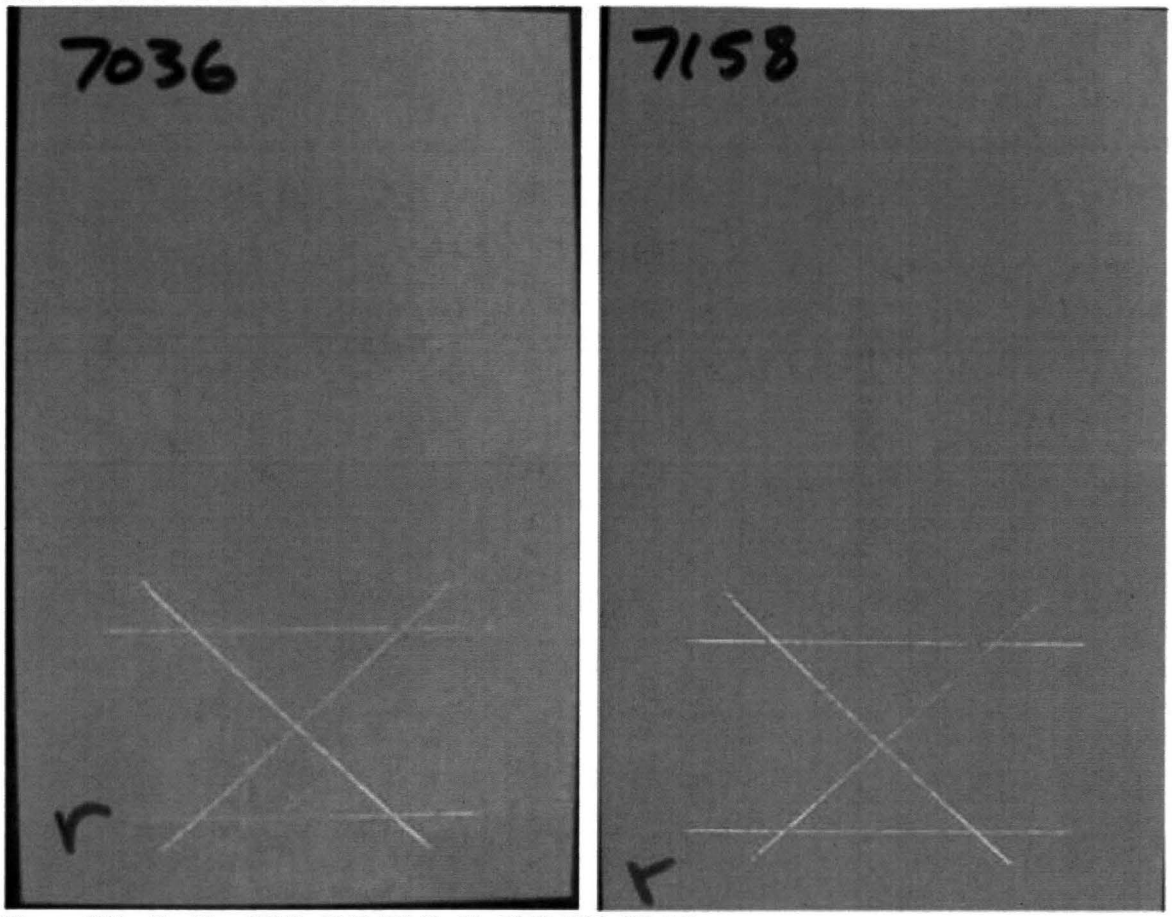

Figure 222 – SurTec 650C; 6061-T6 (Left), 5052-H32 (Right)

Appendix J –
Panel Photographs Immersion Time Study

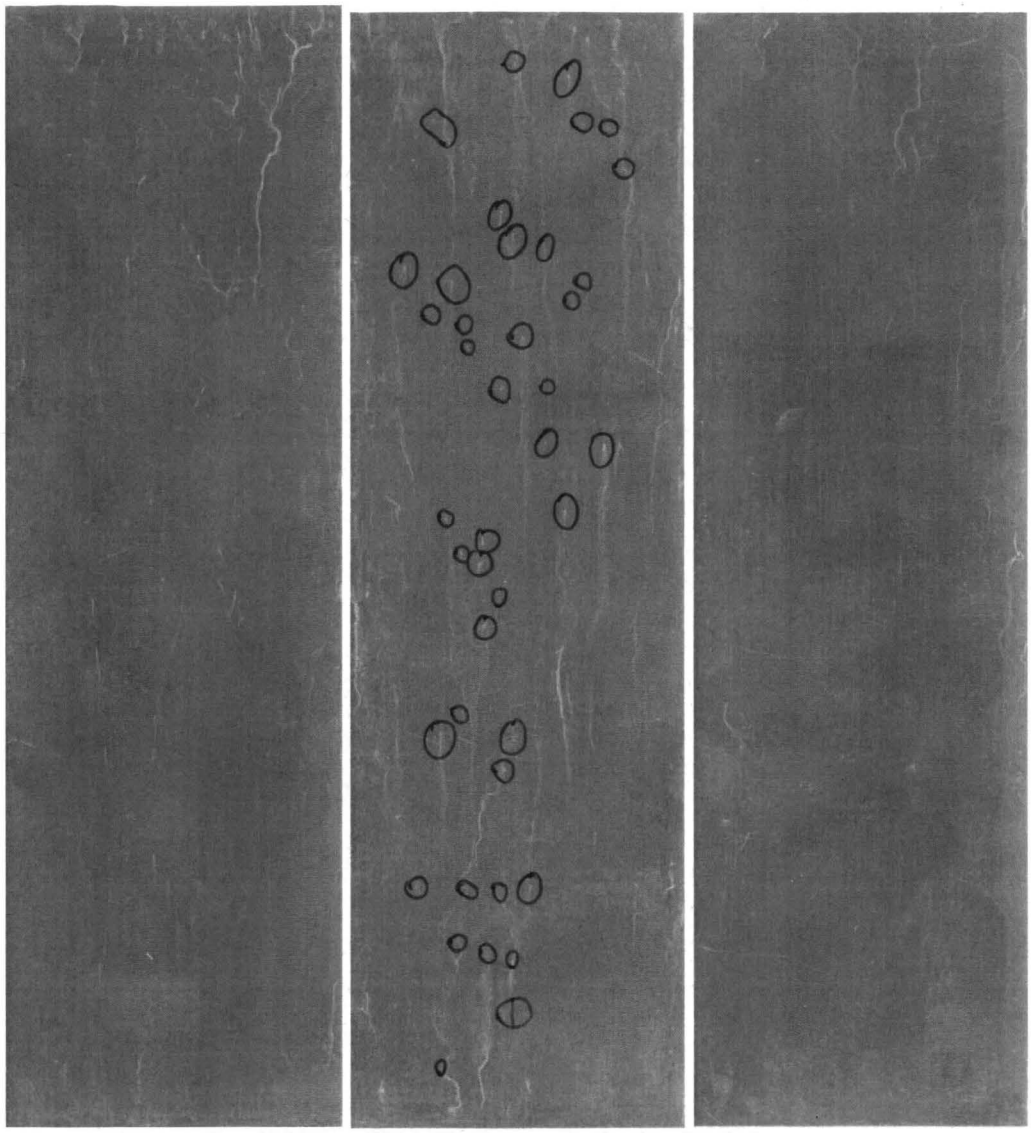

Figure 223 – Alodine 1200S on 2024-T3, Process 2 (3 min., 2 min.)

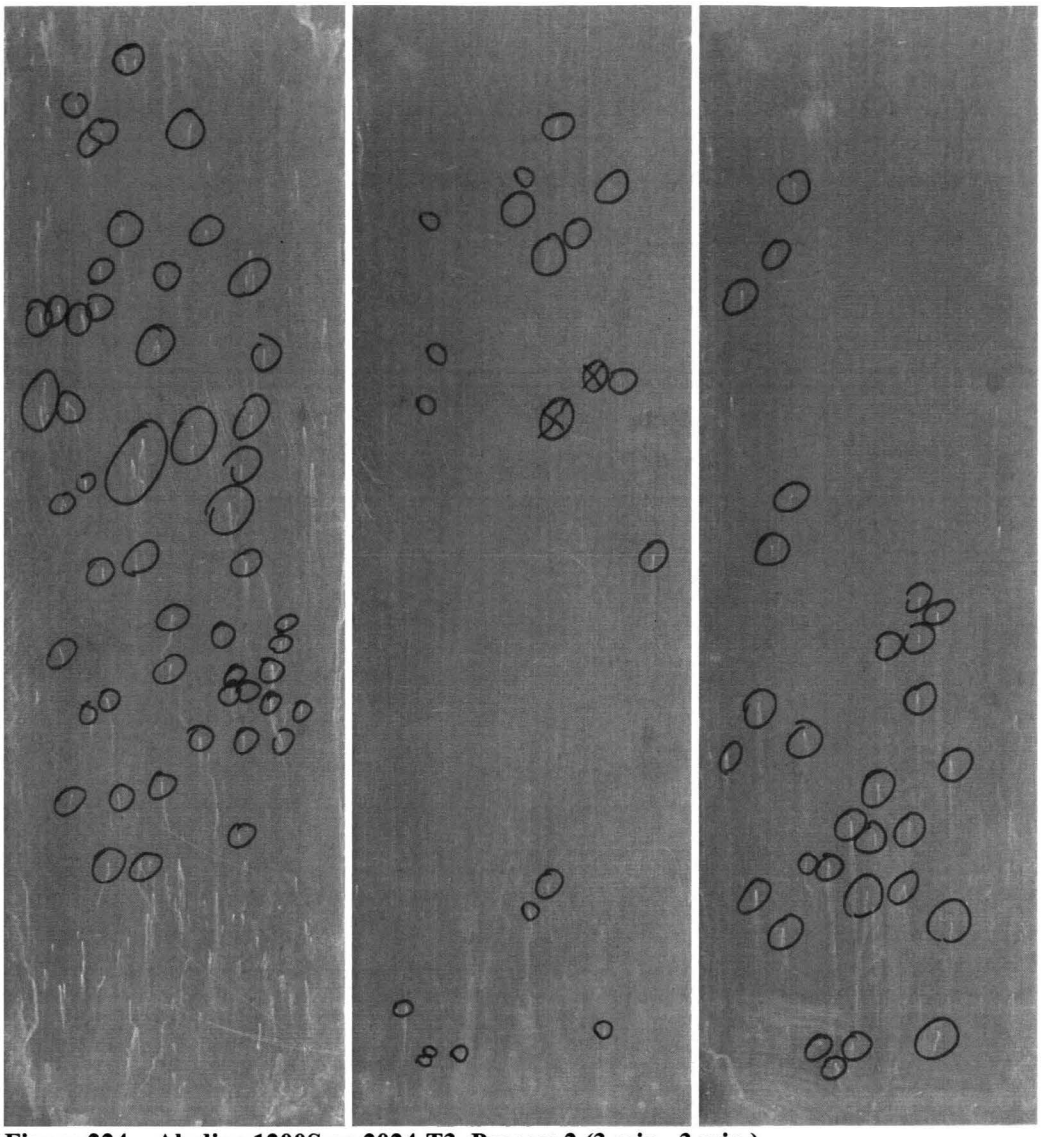

Figure 224 – Alodine 1200S on 2024-T3, Process 2 (3 min., 3 min.)

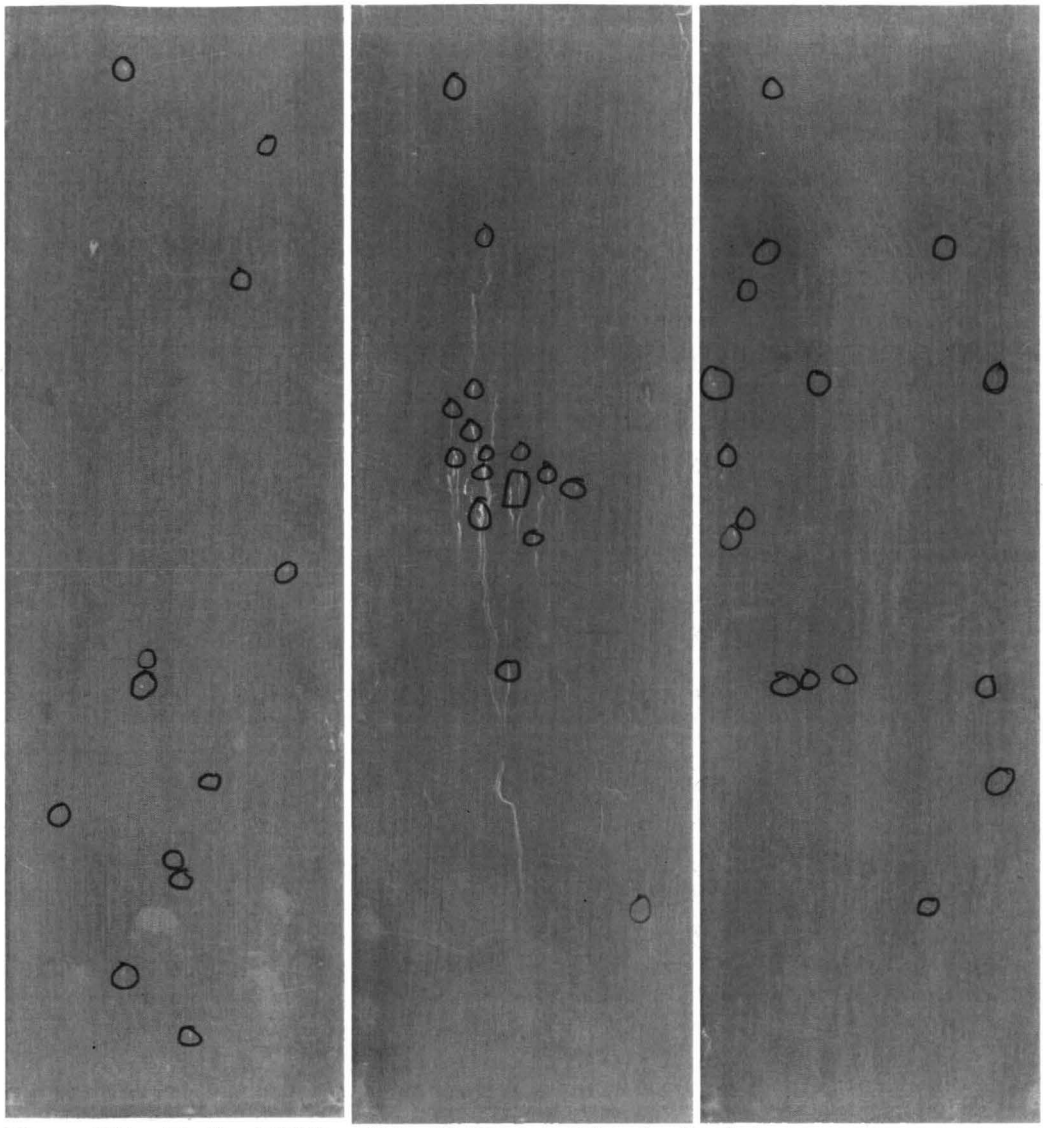

Figure 225 – Alodine 1200S on 2024-T3, Process 2 (5 min., 3 min.)

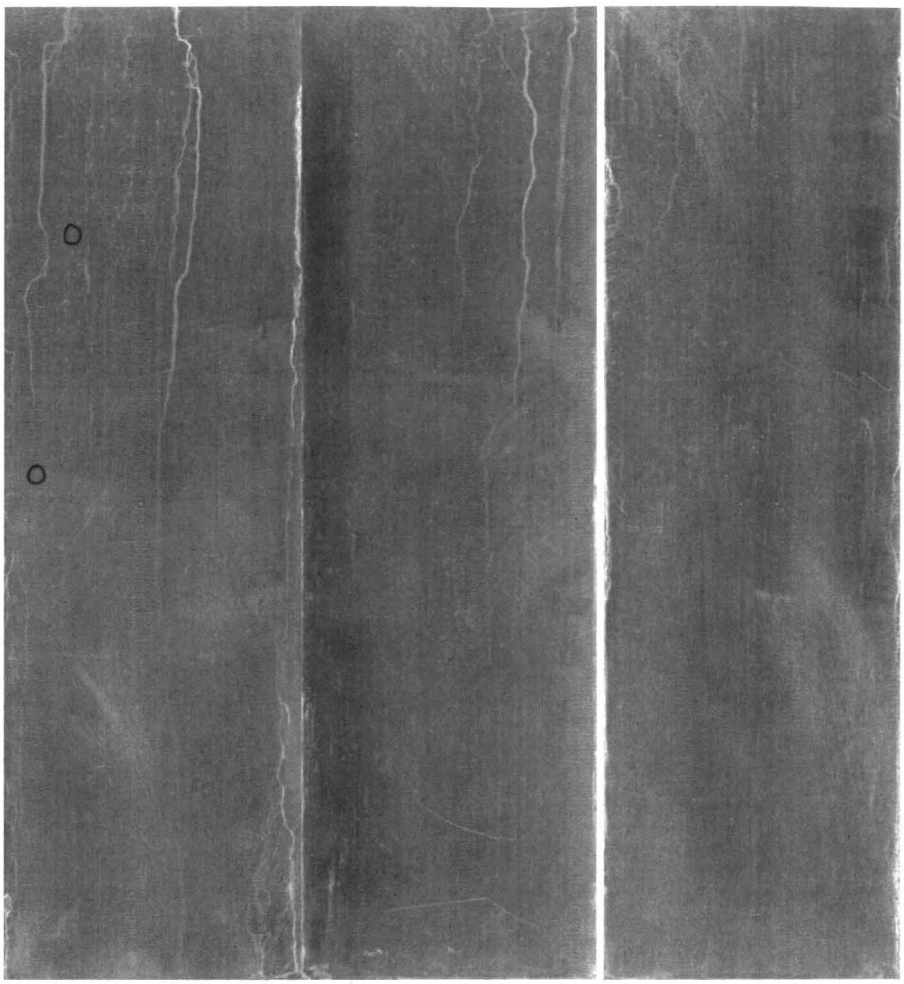

Figure 226 - Alodine 1200S on 7075-T6, Process 2 (3 min., 2 min.)

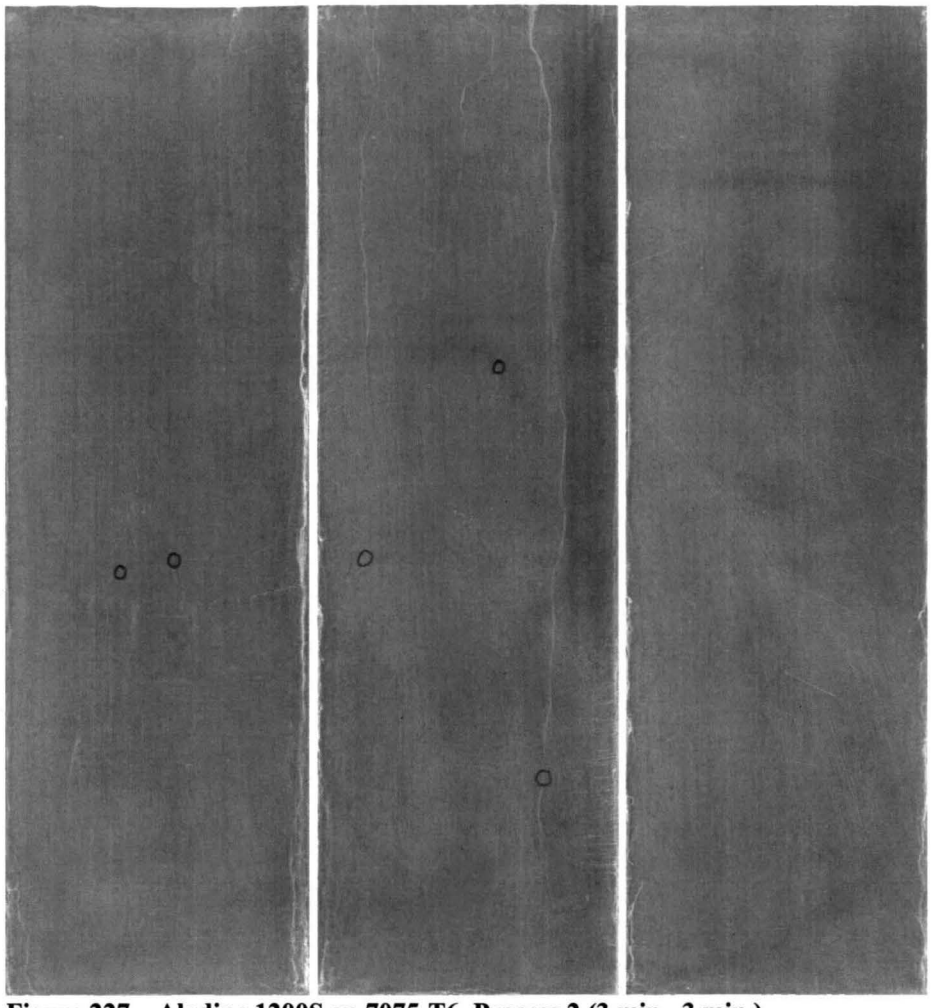

Figure 227 – Alodine 1200S on 7075-T6, Process 2 (3 min., 3 min.)

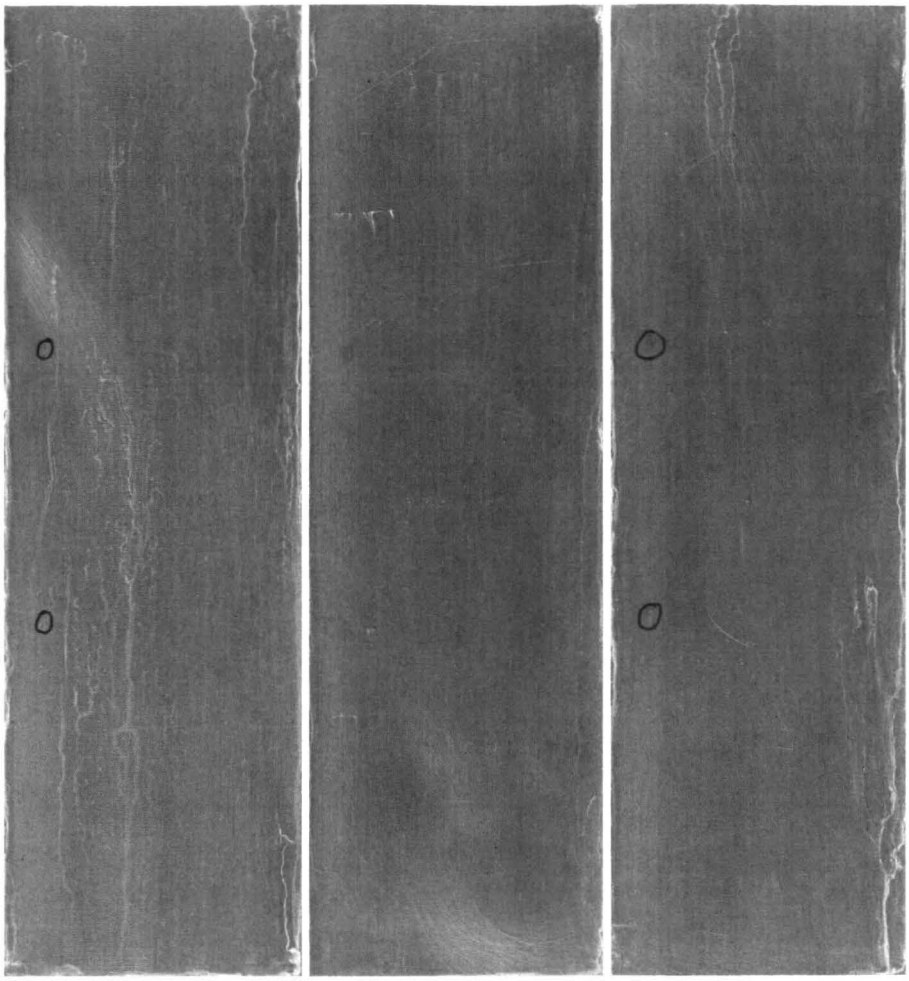

Figure 228 - Alodine 1200S on 7075-T6, Process 2 (5 min., 3 min.)

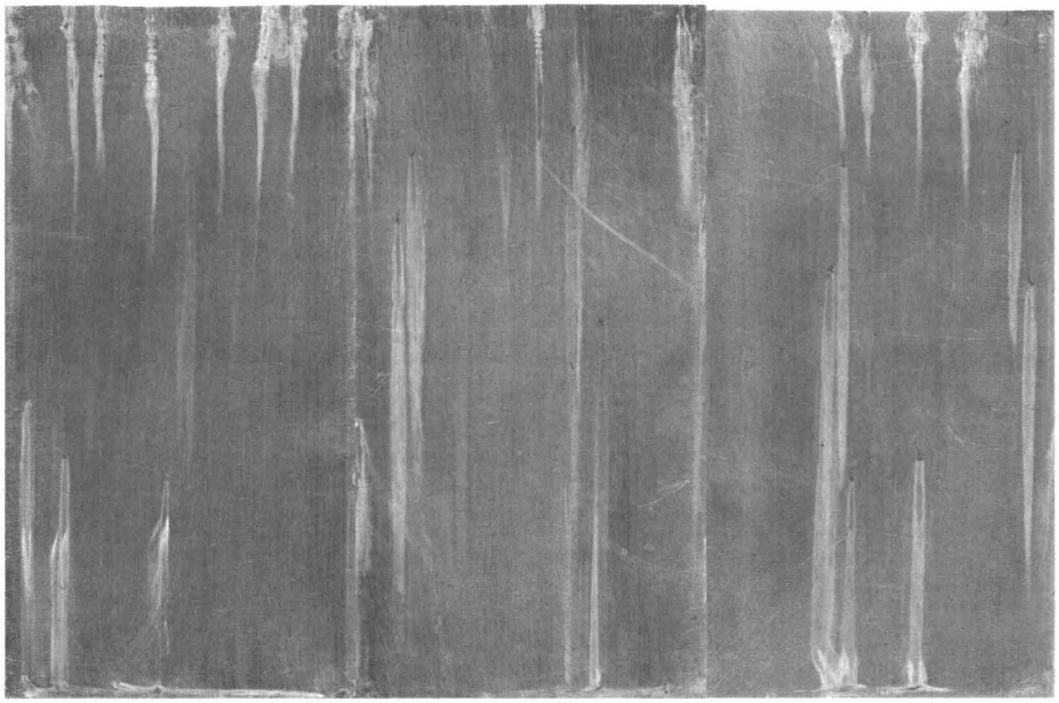

Figure 229 – Alodine 1200S on 2219, Process 2 (3 min., 3 min.)

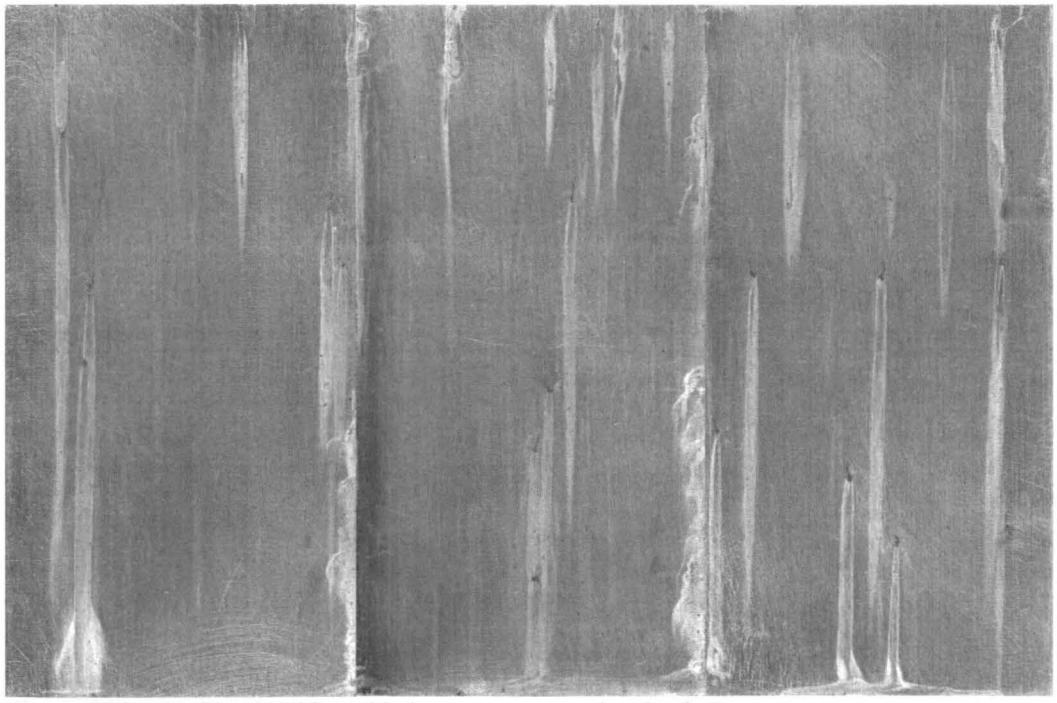

Figure 230 – Alodine 1200S on 2219, Process 2 (5 min., 3 min.)

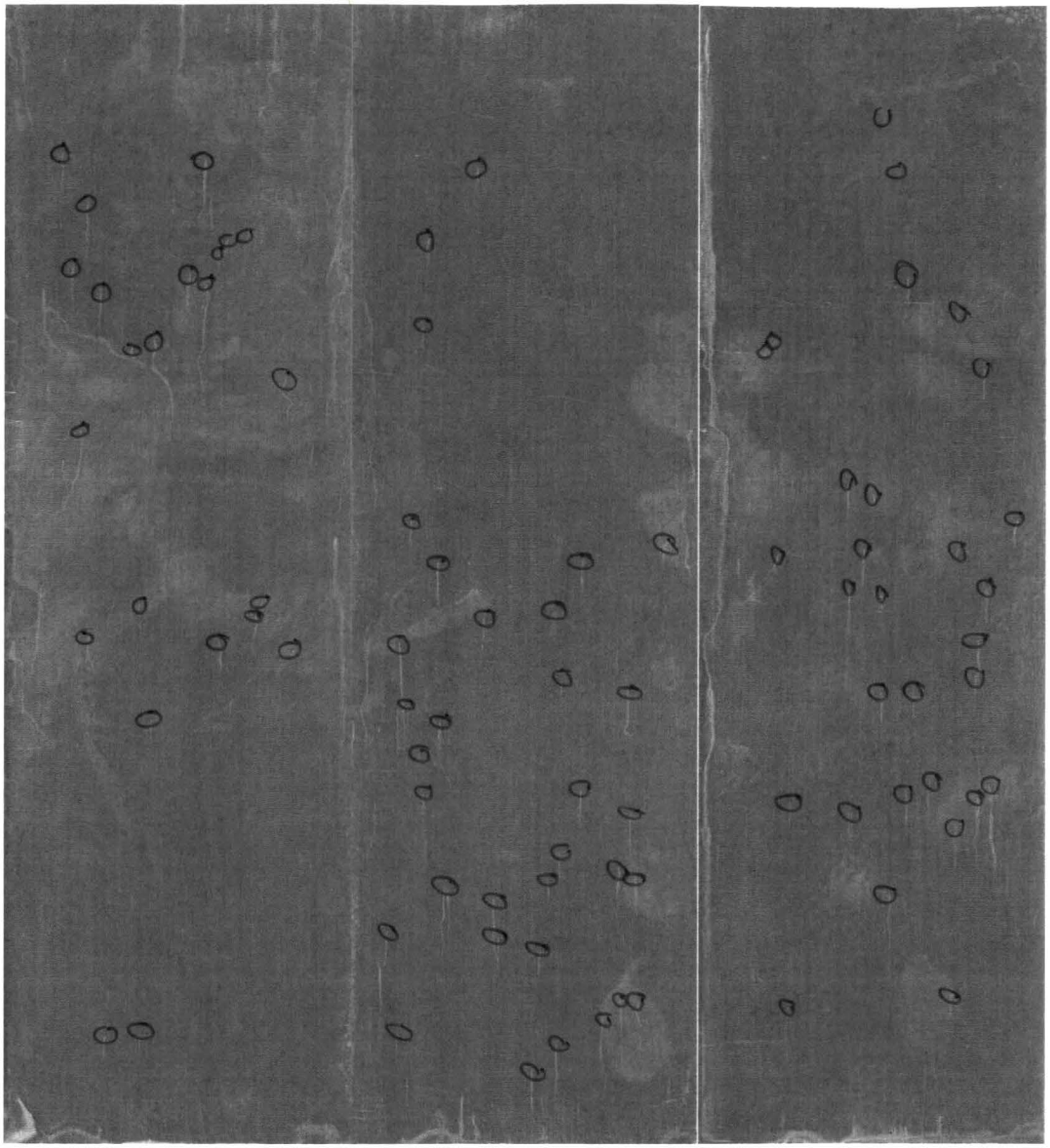

Figure 231 – Metalast HF on 2024-T3, Process 1 (1 min. deoxidizer)

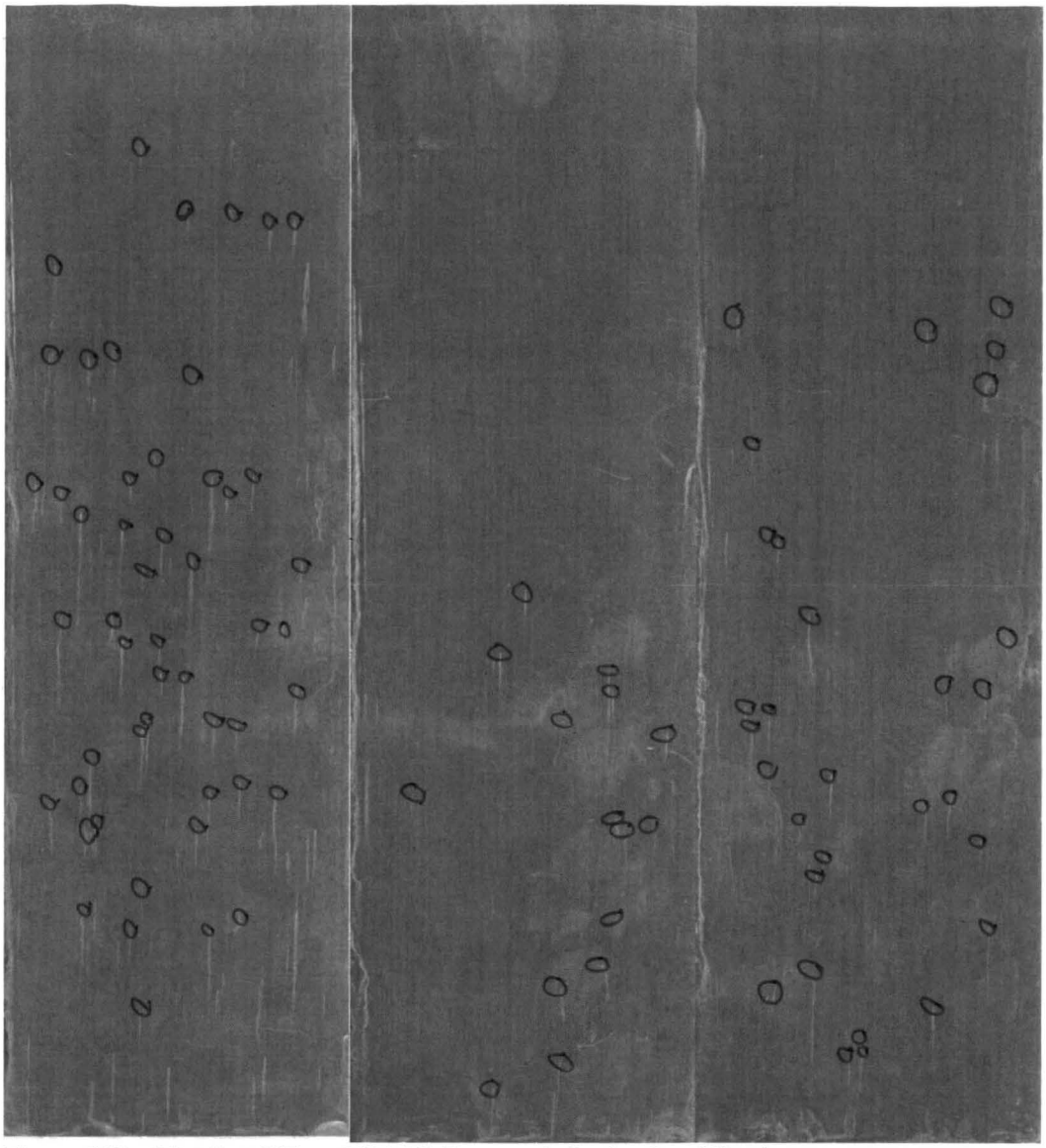

Figure 232 – Metalast HF on 2024-T3, Process 1 (2 min. deoxidizer)

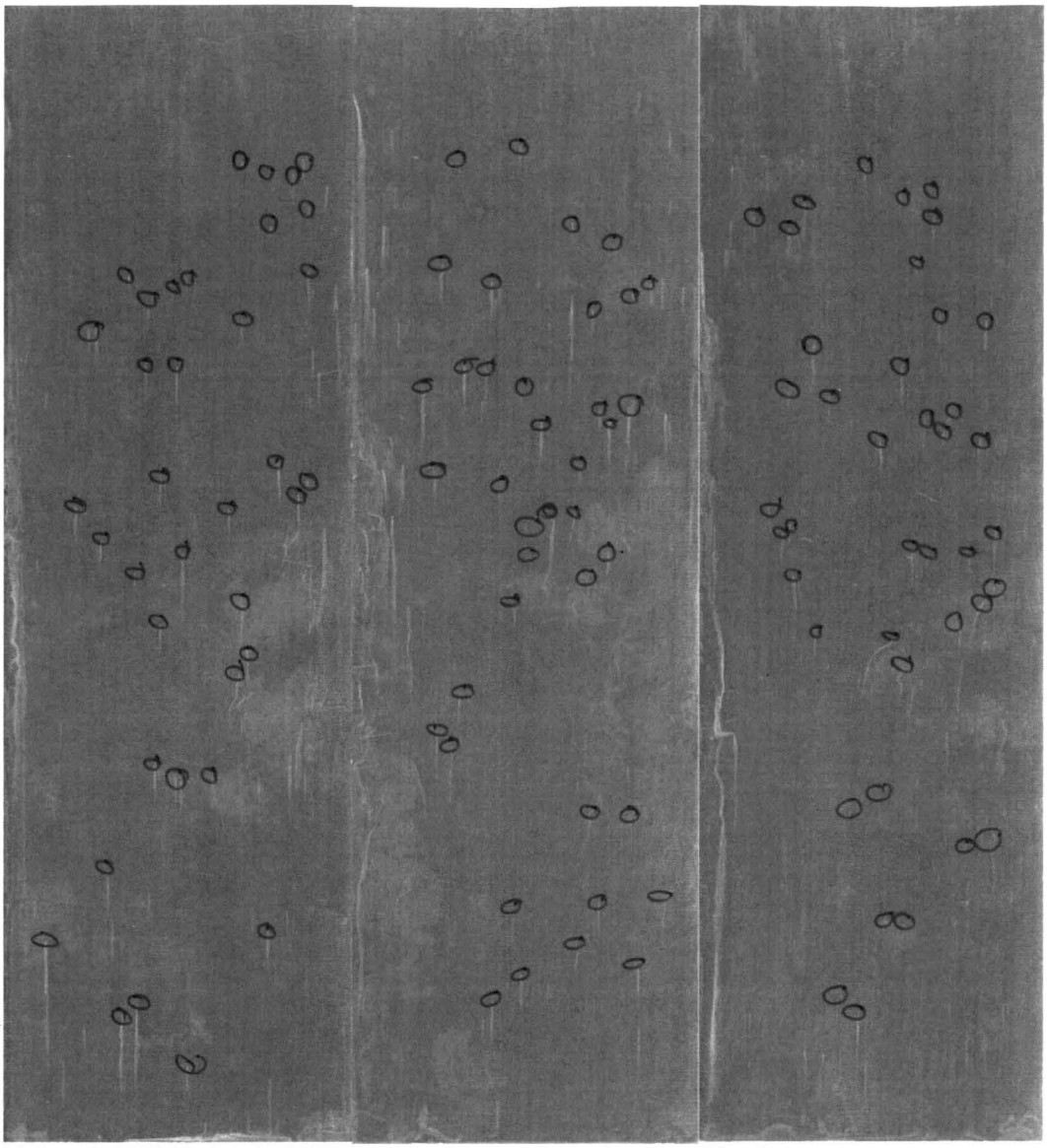

Figure 233 – Metalast HF on 2024-T3, Process 1 (3 min. deoxidizer)

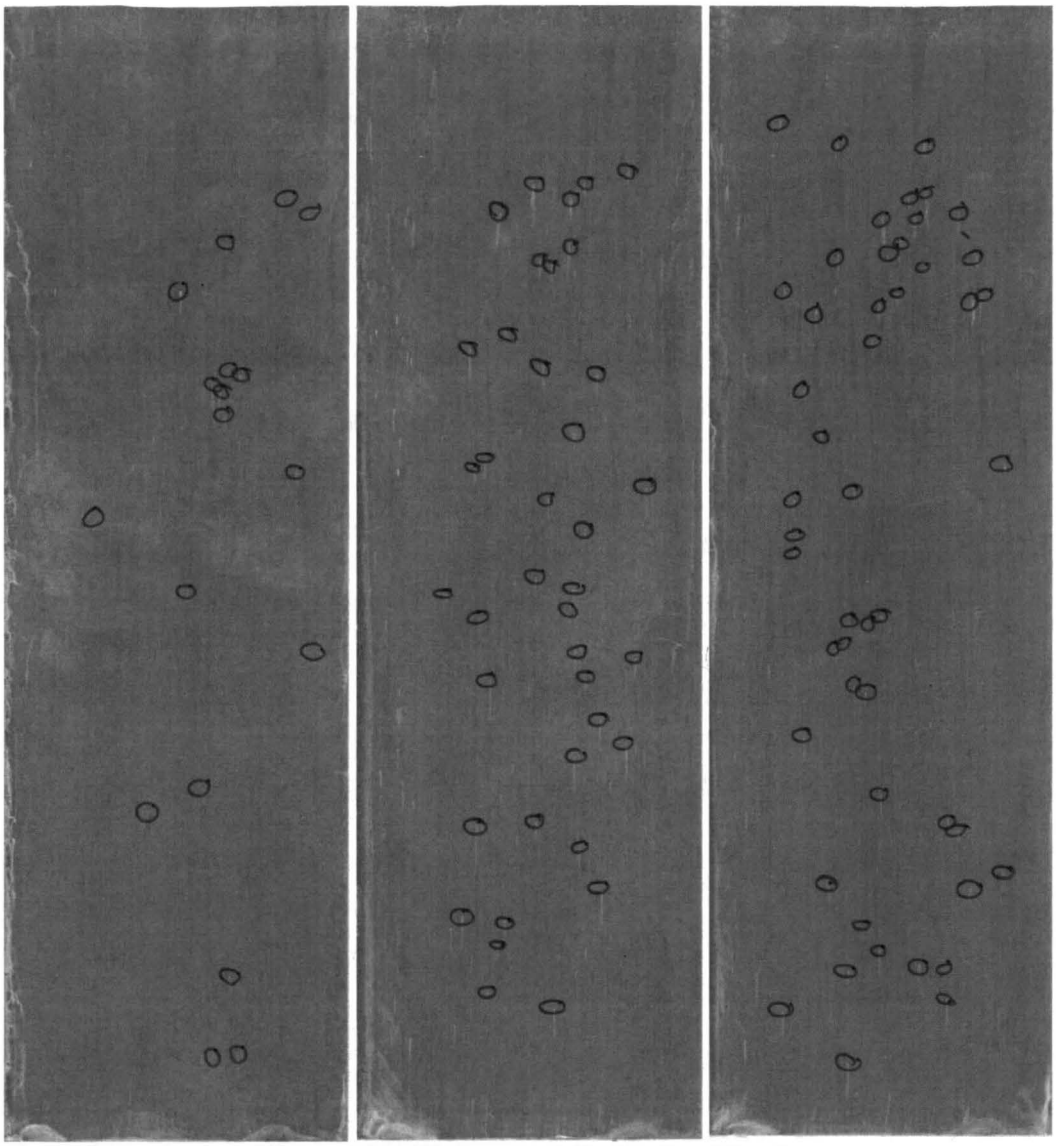

Figure 234 – SurTec 650C on 2024-T3, Process 1 (1 min. deoxidizer)

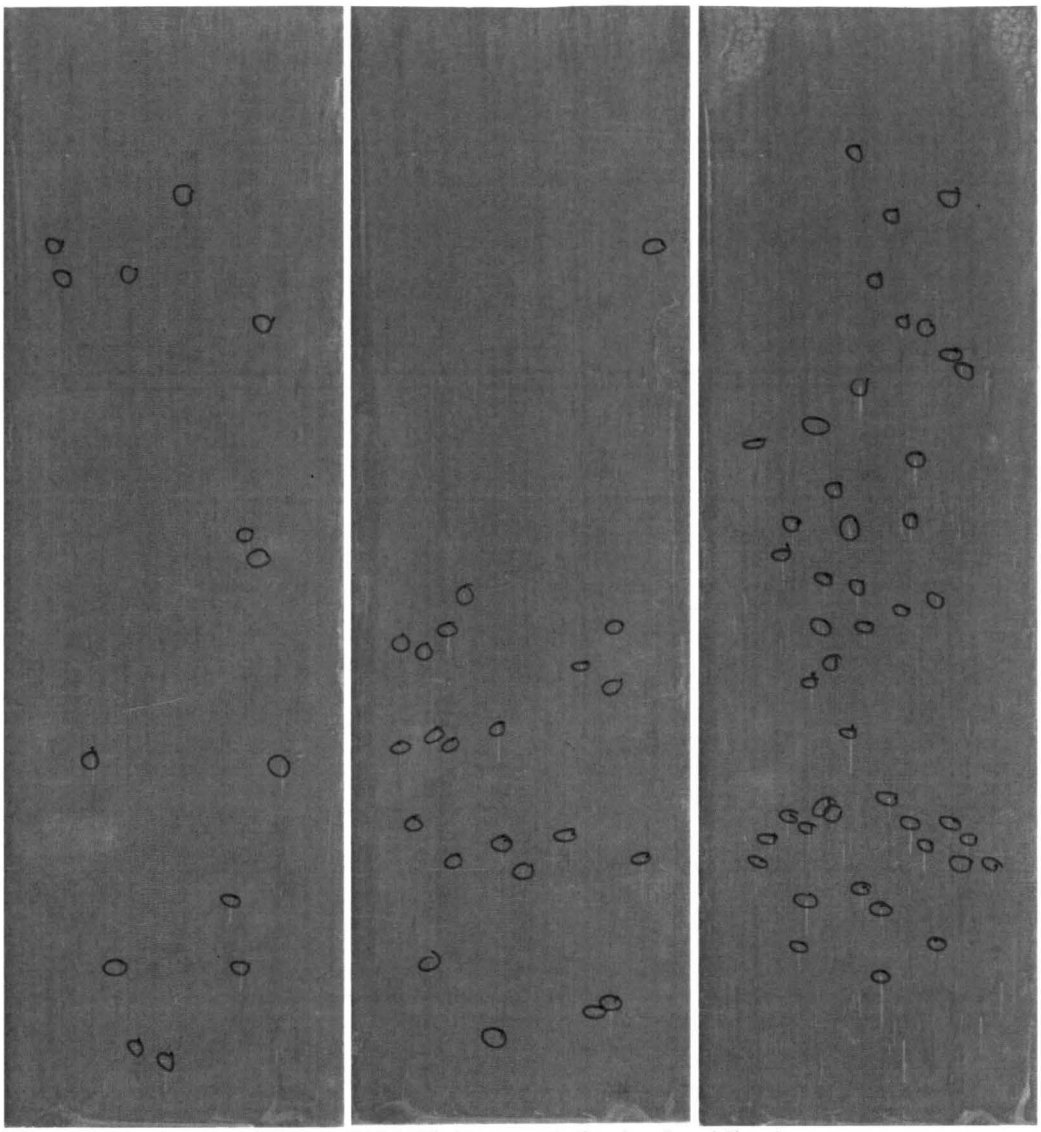

Figure 235 – SurTec 650C on 2024-T3, Process 1 (2 min. deoxidizer)

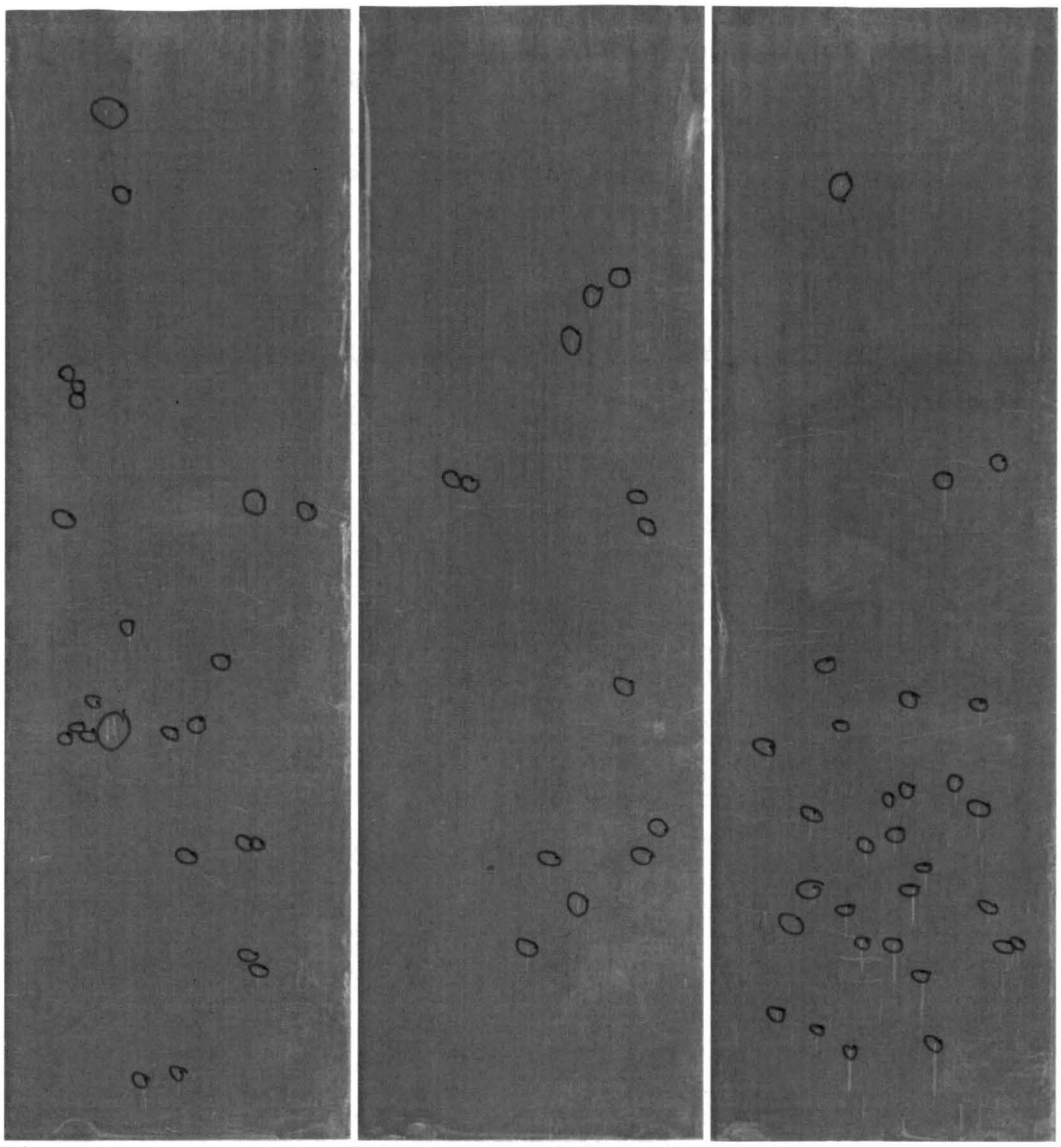

Figure 236 – SurTec 650C on 2024-T3, Process 1 (3 min. deoxidizer)

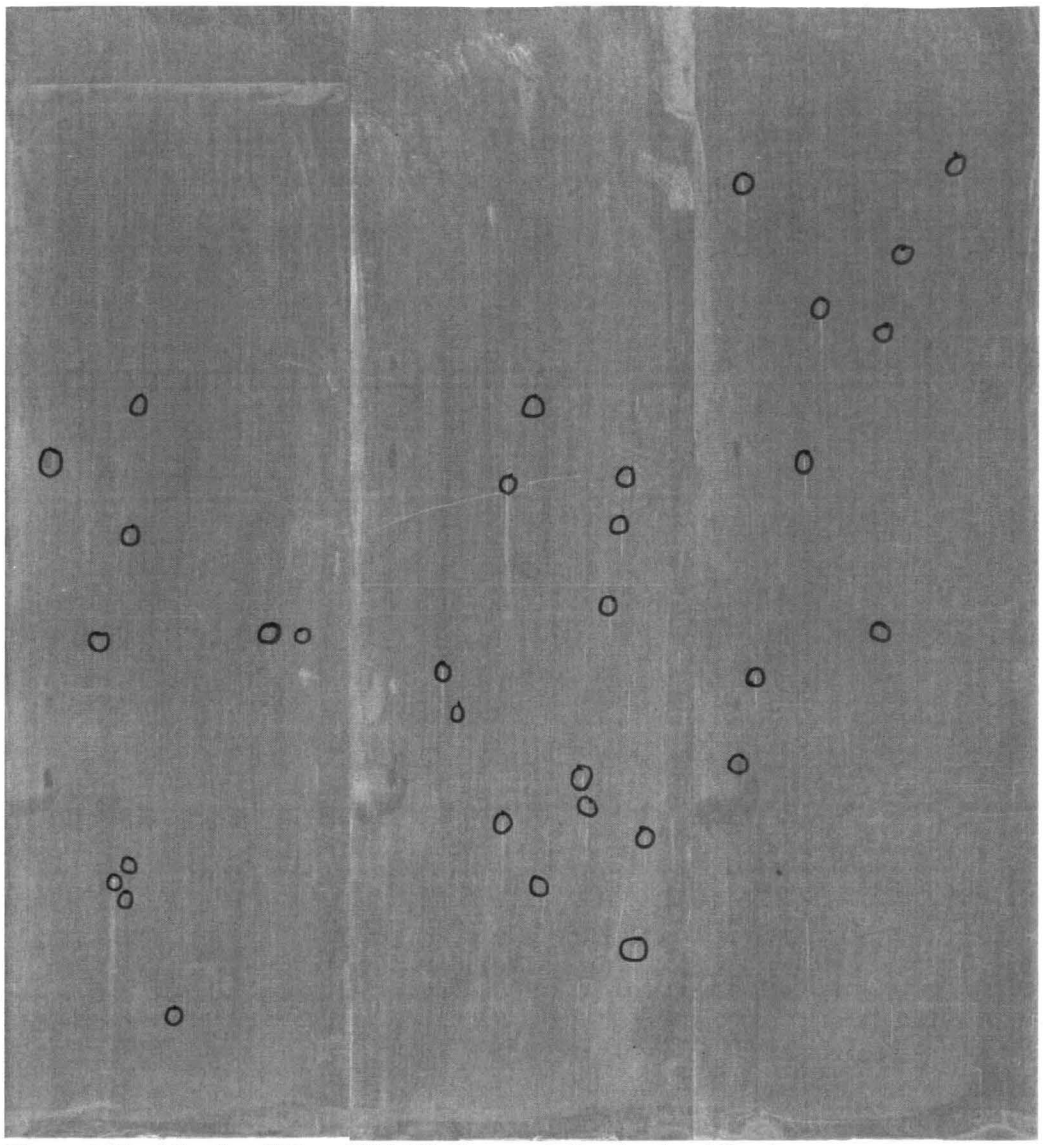

Figure 237 – Metalast HF on 2024-T3, Process 2 (1 min. deoxidizer)

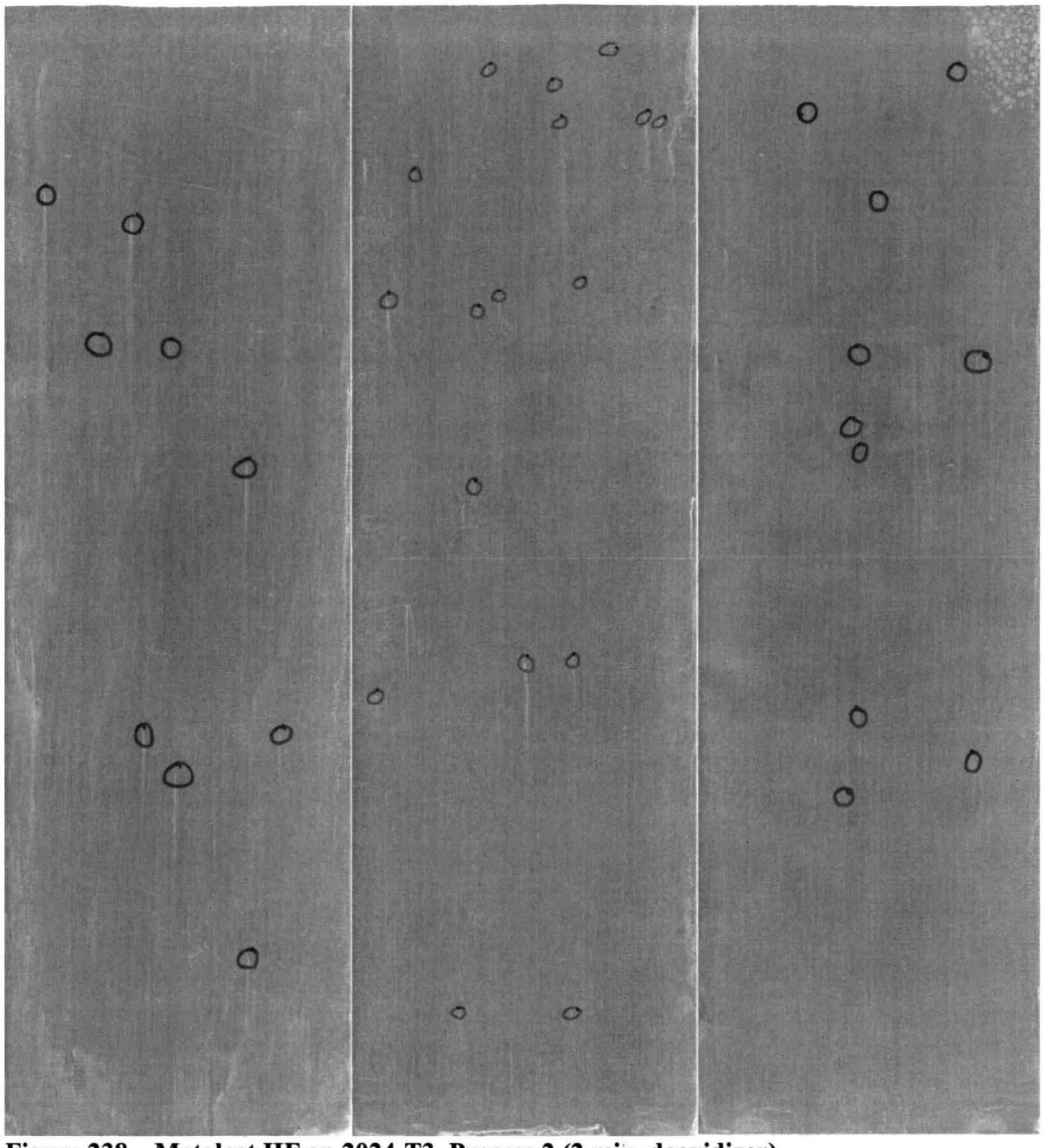

Figure 238 – Metalast HF on 2024-T3, Process 2 (2 min. deoxidizer)

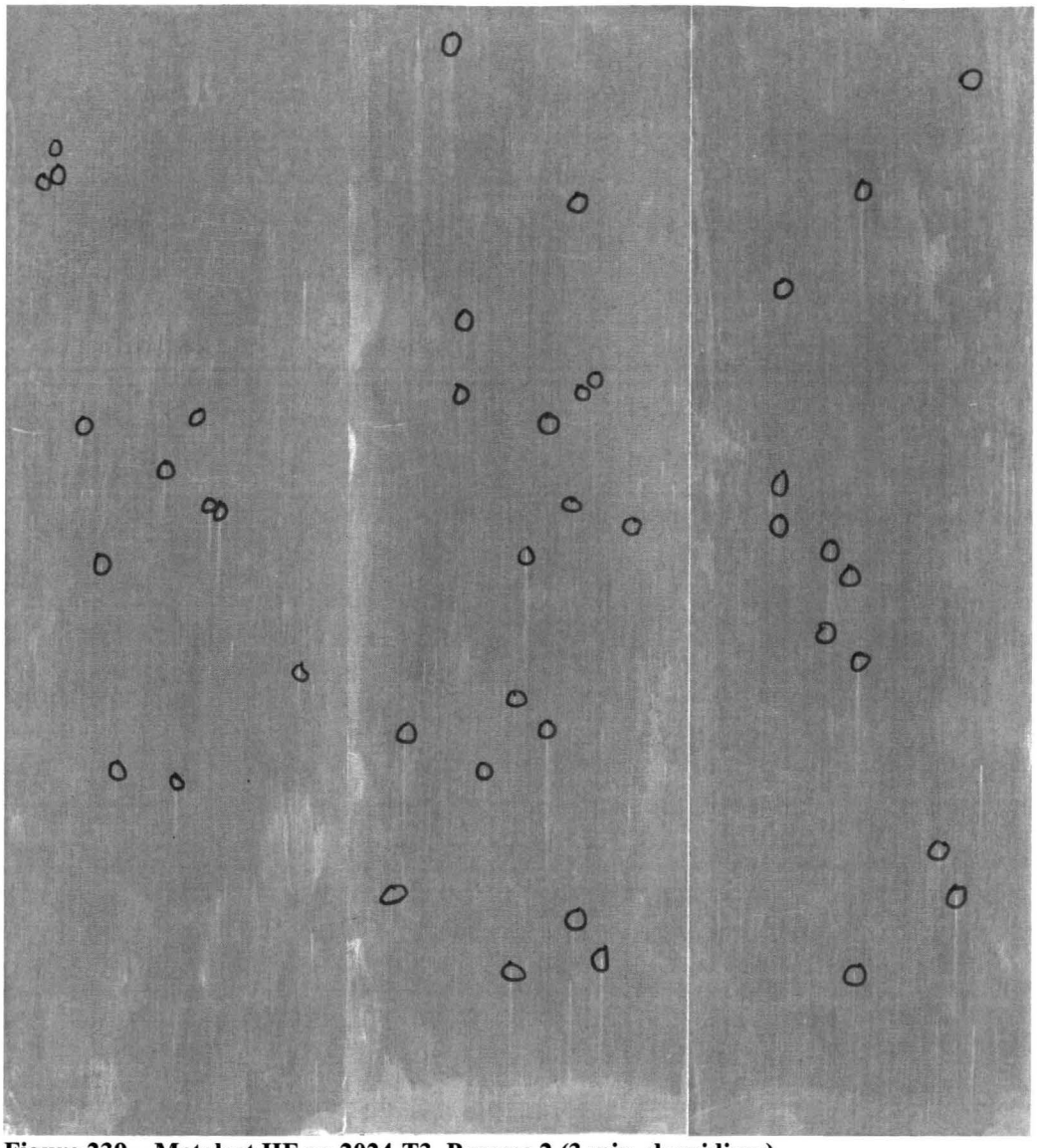

Figure 239 – Metalast HF on 2024-T3, Process 2 (3 min. deoxidizer)

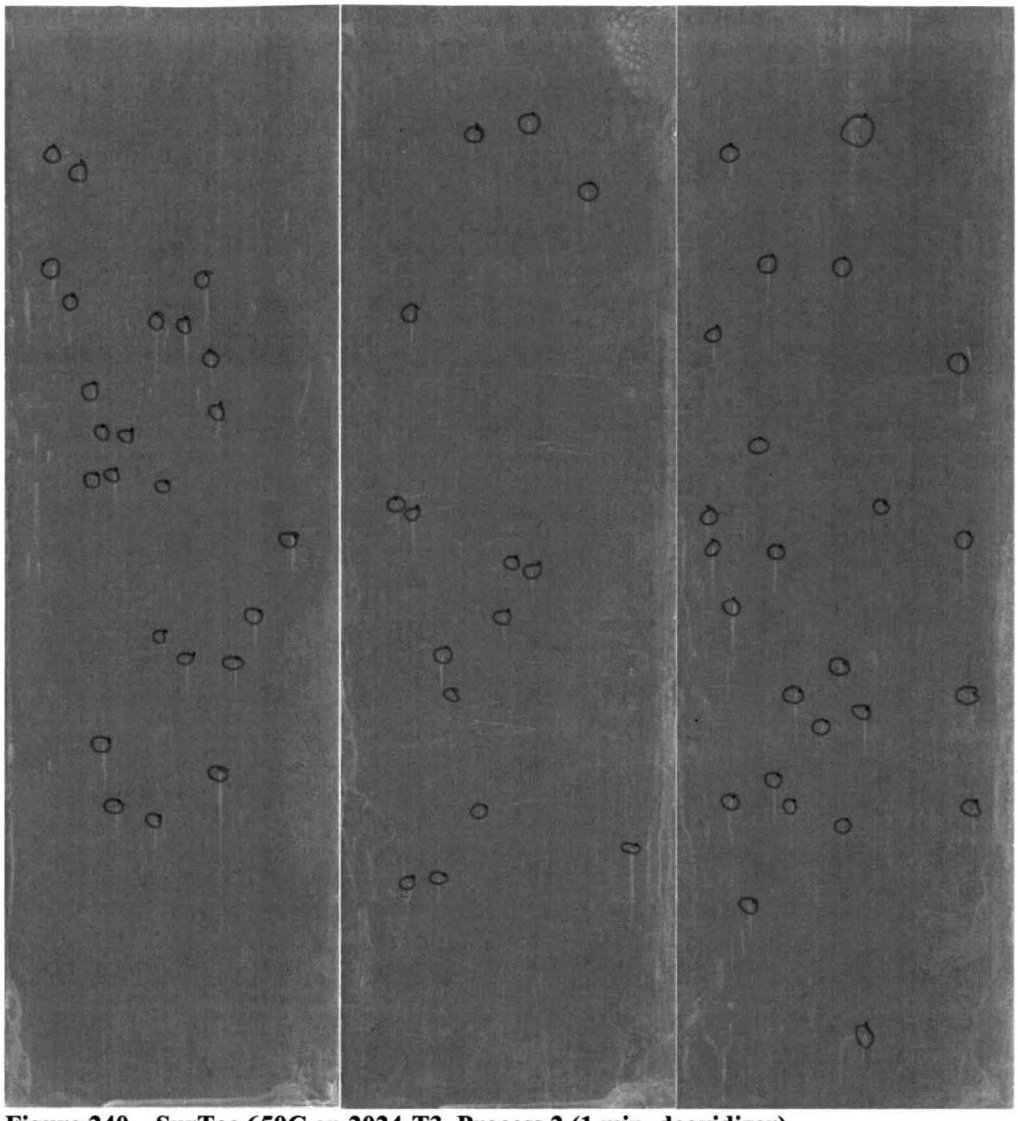

Figure 240 – SurTec 650C on 2024-T3, Process 2 (1 min. deoxidizer)

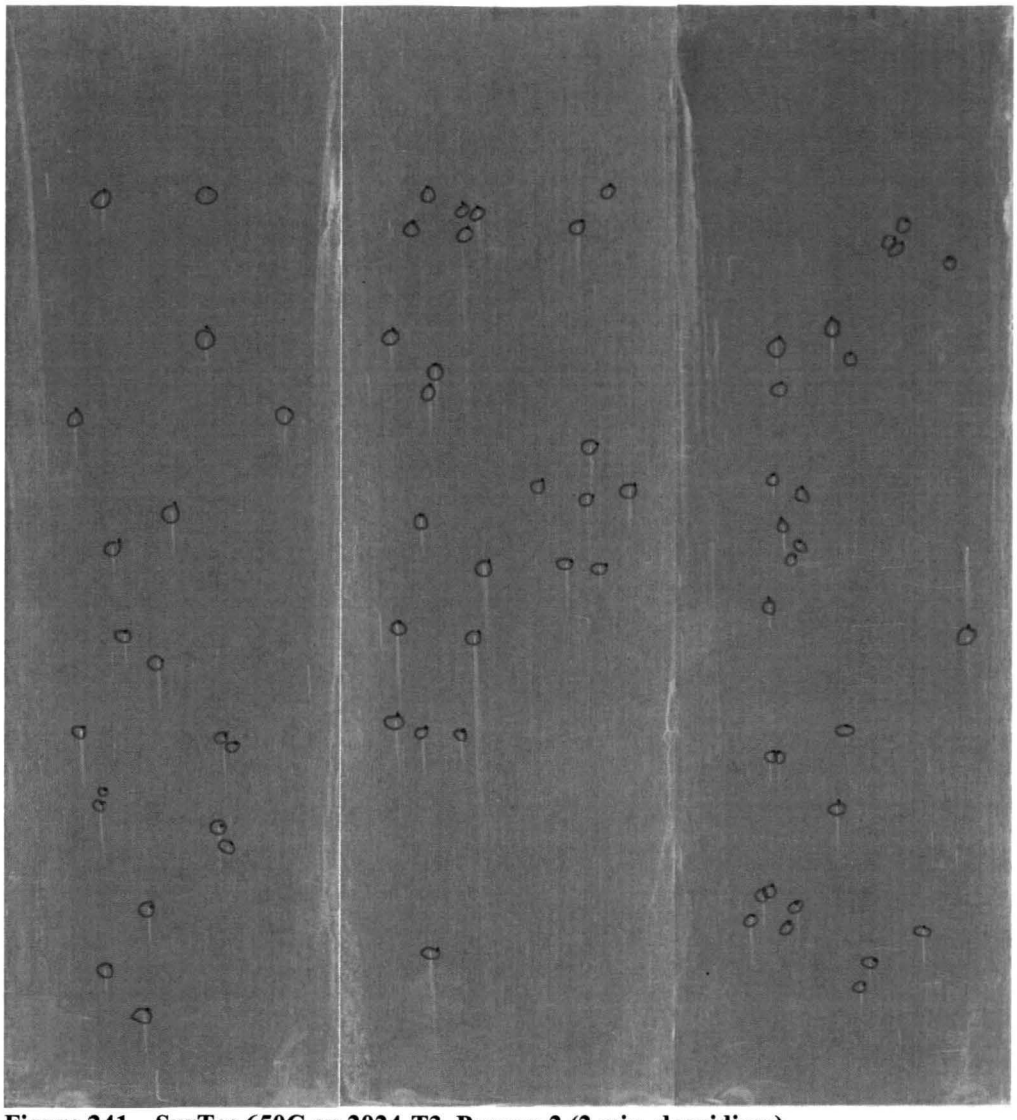

Figure 241 – SurTec 650C on 2024-T3, Process 2 (2 min. deoxidizer)

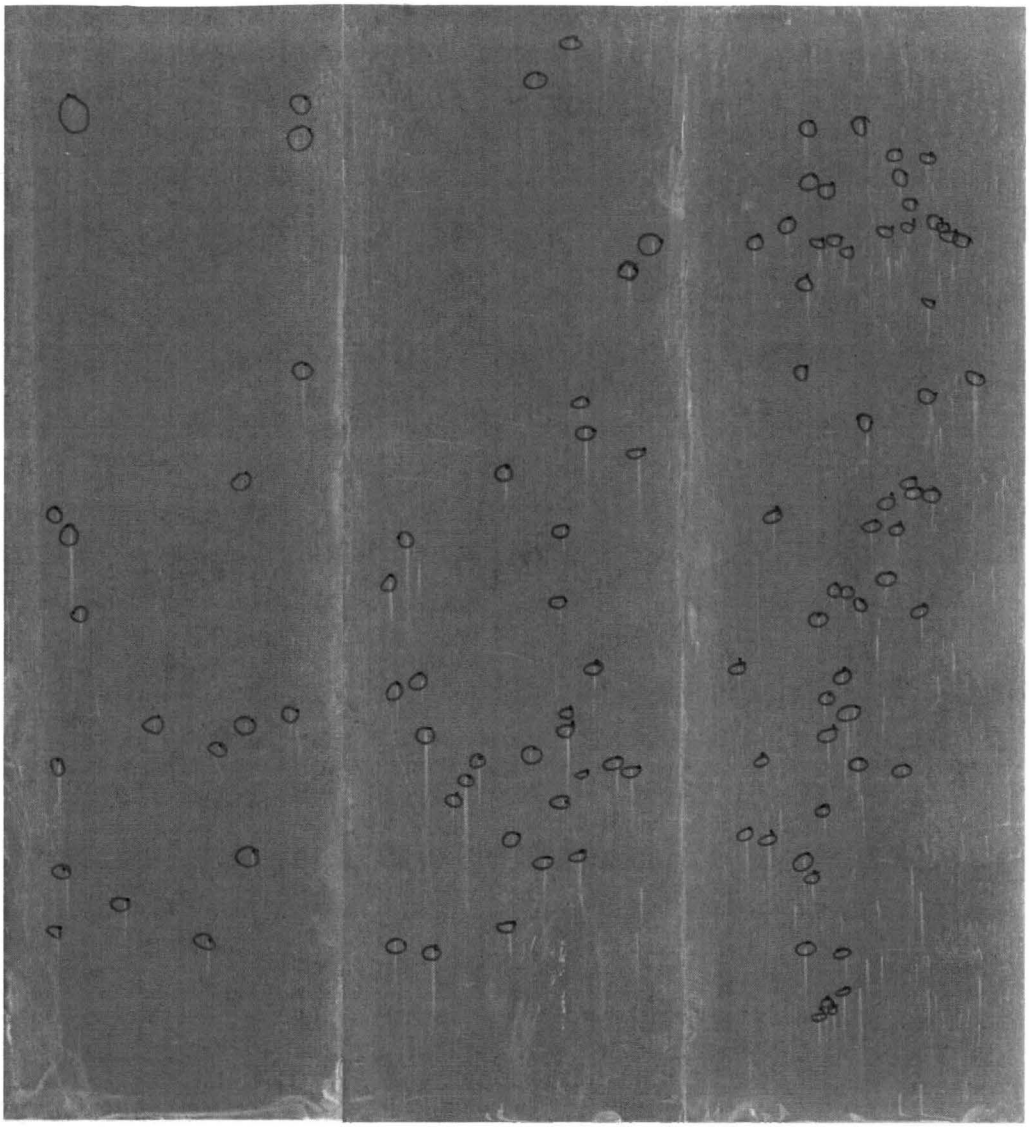

Figure 242 – SurTec 650C on 2024-T3, Process 2 (3 min. deoxidizer)